A COMPARATIVE STUDY BETWEEN RANGE-BASED AND RANGE-FREE LOCALIZATION PROTOCOLS

BY

ESSA QASEM SHAHRA

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This thesis, written by **ESSA QASEM SHAHRA** under the direction of his thesis adviser and approved by his thesis committee, has been presented to and accepted by the Dean of Graduate Studies, in partial fulfillment of the requirements for the degree of **MASTER OF SCIENCE IN COMPUTER NETWORKS**.

Thesis Committee

Dr. Tarek Rahil Sheltami (Adviser)

Dr. Basem Al-Madani (Member)

Dr. Muhammad Mahmoud (Member)

Dr. Ahmad Al-Mulhem
Department Chairman

Dr. Salam A. Zummo
Dean of Graduate Studies

3/1/12

Date

To my Father

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LIST OF ABBREVIATIONS

MEMS	Micro-electro-mechanical System
WSN	Wireless Sensor Network
IoTs	Internet of Things
OS	Operating System
SN	Sensor Network
SS	Signal Strength
TOA	Time of Arrival
GUI	Geographical User Interface
GPS	Global Positioning System
RSS	Receive Signal Strength
CL	Centroid Localization
RSSI	Receive Signal Strength Indication
LS	Linear Square

TDoA	Time Different of Arrival
AoA	Angle of Arrival
MDS	Multidimensional Scaling
CTA	Closer tracking Algorithm
BS	Base Station
MT	Mobile Target
RP	Reference point
RF	Radio Frequency
PT	Power Transmission
PR	Power Receiving
MDSMAP	Multi Dimensional Scaling Mobile Assisted Programming
SDP	Semi Definite Programming
AP	Access Point
DB	Database
EF	Environment Factor

THESIS ABSTRACT

NAME:	Essa Qasem Shahra
TITLE OF STUDY:	A Comparative Study Between Range-based and Range-free Localization Protocols
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Sensor networks are applied in a numerous number of applications. However, implementing wireless sensor networks presents new challenges. Cooja is a Contiki network simulator, which allows small and large networks of Contiki motes to be simulated; moreover, motes can be emulated at the hardware level. Recently, localization and tracking issues are drawing a notable consideration in WSNs due to the need of achieving high localization accuracy at low power consumption. The existing localization protocols are classified into two types: range-free and range-based. In this thesis, we evaluate the accuracy and the power performance of four very well-known localization protocols, namely: RSSI, fingerprint, centroid and DV-Hop protocols using Tmote sky in Cooja. However; any other type of motes could be used. It is worth mentioning that this the first time this study

is conducted in Cooja. The results confirm with the theory that range-based protocols have the best performance than range-free in terms of localization accuracy. However, in term of stability and power consumption, range-free protocols outperform range-based protocols.

ملخص الرسالة

الأسم الكامل: عيسى قاسم ناجي شحرة

عنوان الرسالة: دراسة مقارنة بين بروتوكولات تحديد المواقع Range-based and Rang-free protocols

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يمكن استخدام شبكات الاستشعار الاسلكي في العديد من التطبيقات المختلفة. كما أن بناء وتركيب هذا النوع من الشبكات الاستشعاريه يمثل تحدياً جديداً. COOJA هي أداة أو تطبيق يستخدم لمحاكاة الشبكات الاستشعارية الاسلكية وتُضمن هذه الأداة ضمن حزمه نظام التشغيل CONTIK.وهو عبارة عن نظام تشغيل صمم خصيصاً للعمل على الأجهزة الصغيره (المتحسسات) ذوات الإمكانيات المحدوده من حيث المعالجة واستهلاك الطاقة.

يسمح هذا النوع من أداوات المحاكاة في بناء ومحاكاة الشبكات الصغيرة والكبيرة الحجم التى تحتوي على عدد كبير من المتحسسات المختلفة, كما أنه يسمح بمحاكاتها على المستوى المادي. حديثاً عملية التتبع وتحديد المواقع حضت باهتمام كبير في مجال شبكات الاستشعار الاسلكي وذلك لأهمية وضرورة الحصول على دقة عالية في تحديد المواقع للأجسام المتحركة في ظل استهلاك محدود ومنخفض للطاقة. يمكن تصنيف بروتوكولات تحديد المواقع داخلياً الى صنفين: Range-based and Range-free.

في هذة الأطروحة عملنا على تقييم أداء هذا النوع من البروتوكولات بناءً على عاملي الدقة واستهلاك الطاقة وقد شملت دراستنا أربعه أنواع من البروتوكولات هي :RSSI, Fingerprint, centroid, DV-Hop باستخدام المتحسسات Tmotesky وقد تمت عملية التمثيل البرمجي والبناء الشبكي لهذة البراوتوكولات عبر أداة المحاكاة المسماه COOJA كما أنه يمكن استخدام أنواع أخرى من المتحسسات ولايقتصر العمل على النوع المذكور سابقا من المتحسسات. الجدير بالذكر بأن هذة هي أول دراسة تنفذ بهذا المجال عبر اداة المحاكاة COOJA.

وقد أظهرت النتائج بأن كل ماتم ذكره بالجانب النظري حول البروتوكولات المذكورة سابقاً قد تم التحقق منه والحصول على نتائج عملية مطابقة له تماماً, وأظهرت النتائج ان بروتوكولات Range-based هي الأفضل من حيث الحصول على دقة عاليه في تحديد المواقع ولكنها ذو كلفة باهضة لكونها قد تحتاج إلى مكونات مادية وأجهزة أضافية لتنفيذها . بينما بروتوكولات Range-free هي الأفضل من حيث الأداء والاستقرار والثبات في استهلاك الطاقة, بالإضافة الا انها ذات تكلفة أقل لكونها لاتستلزم أي متطلبات أو معدات اضافية.

CHAPTER 1

INTRODUCTION

With the exponential growth in the technology of micro-electro-mechanical system (MEMS), wireless networking and wireless sensor networks (WSN) are consequently improving [1]. WSN is the base of Internet of Things (IoTs) [2] [3]. The recent developments in low-control wireless technology motivated us to consider WSN in our work [4]. WSN is constructed of various wireless sensor nodes, which shape a sensor field and a sink. These sets of fields and sinks have the capabilities to sense their surrounding environment, perform a constrained calculation and communicate wirelessly to form WSNs [5]. Moreover a sensor device, called MOTE, performs functions independently and can forward information, process data and communicate wireless with other nodes. A gateway is another part of the network that can be implemented using a more advanced device such as laptop or stationary computer. This device is used to connect the WSN to the other networks, such as the internet and is normally called a SINK node as shown in figure 1.1 [6]. The low-cost of sensor network is the most important characteristic that

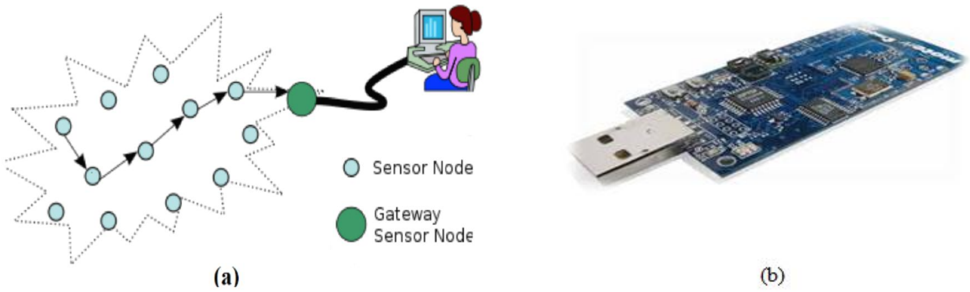

Fig. 1.1: (a) Structure of WSN (b) TmoteSky Sensor[9]

makes it useful for a large number of applications. Nodes have limited resources in terms of power, processing units and communication transmission power [7].

In addition to one or more sensors, a mote usually consists of a wireless transceiver, a micro controller, and some kind of energy source, for example a battery. In WSN, nodes can be classified into three categories: an anchor (beacon), localized and unknown. The anchor node has the ability to identify its current position using an equipped GPS device. The localized node is localized manually using network layouts. Lastly, the unknown node is neither localized accurately nor by estimation [8].

1.1 Application of WSN

The applications of WSN are reliable due to their flexibility and adoptability.

Different applications can be developed using WSN, and are classified into several categories [10] [11] [12].

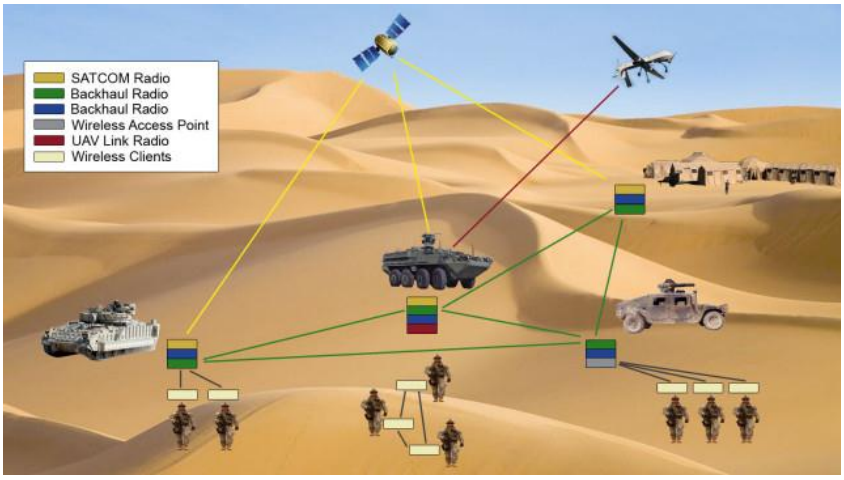

Fig. 1.2: Military WSN application [9].

1.1.1 Military Applications

WSN can be utilized by the military for various purposes, for example, observing and tracking the foes and power safety. Unlike all other networks, WSN fulfills diverse military needs. Due to its qualities like easiness, fast sending, adaptation to internal failure, and self-association, it is very attractive for military application as shown in figure 1.2.

1.1.2 Structural Monitoring Applications

Wireless Sensors are used inside structures and bases like bridges, flyovers, banks, burrows and so on to observe their developments. Subsequently the engineers can now control their resources remotely without going to the site. They can observe remote locations in all times of the day as shown in figure 1.3.

Fig. 1.3: Structural monitoring WSN application [9].

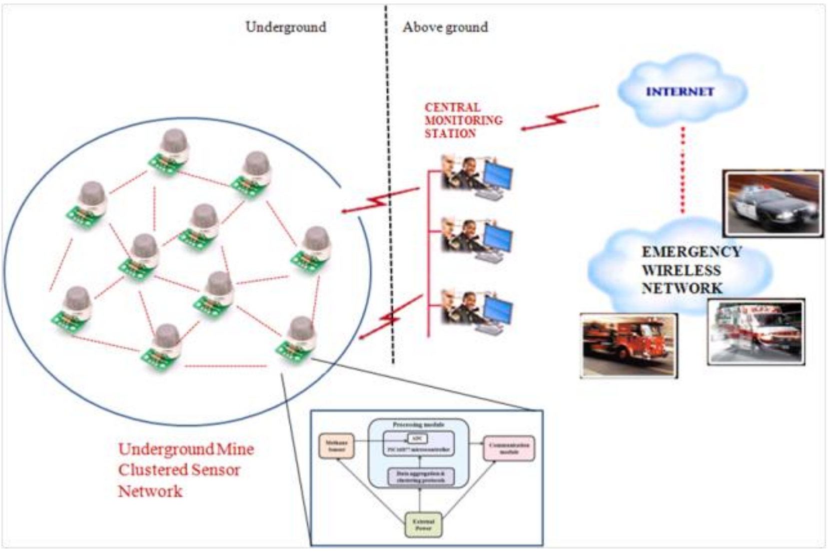

Fig. 1.4: Industrial monitoring WSN application [9].

1.1.3 Industrial Monitoring Applications

Wired sensor network requires wiring and they are very sensitive and fragile. This is not the situation with wireless sensors, which opens new ways that mark its usefulness. WSN are utilized broadly as a part of commercial enterprises to observe apparatus condition and send as shown in figure 1.4.

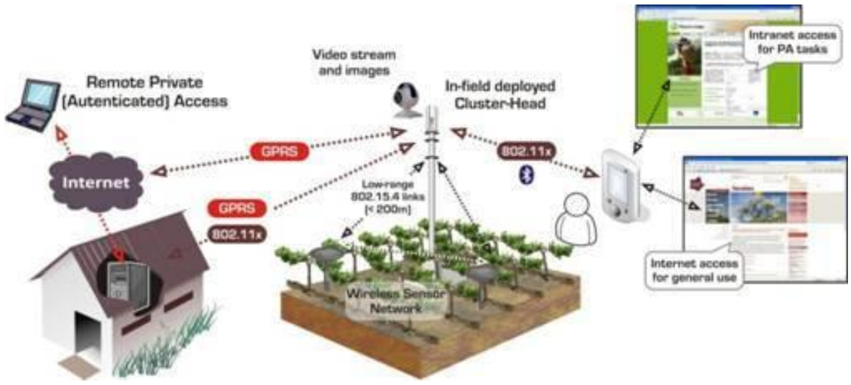

Fig. 1.5: Agriculture monitoring WSN application [9].

1.1.4 Agriculture Sector Applications

This is another sector which where WSNs is beneficial. It is simple to set up a WSN to monitor a few distinct parameters and send alarms and other data to the system as shown in figure 1.5.

1.1.5 Transportation Applications

WSNs make it convenient to gather continuous traffic data by constructing the networks in important locations around the city. It is conceivable to organize dynamic feed with respect to the congestion and movement issues which can then later be sustained on the entrance of a firm for transportation as shown in figure 1.6.

1.1.6 Health Applications

Health applications of sensor networks include giving interfaces to the incapacitated, incorporated patient observing, diagnostics, drug organization in healing

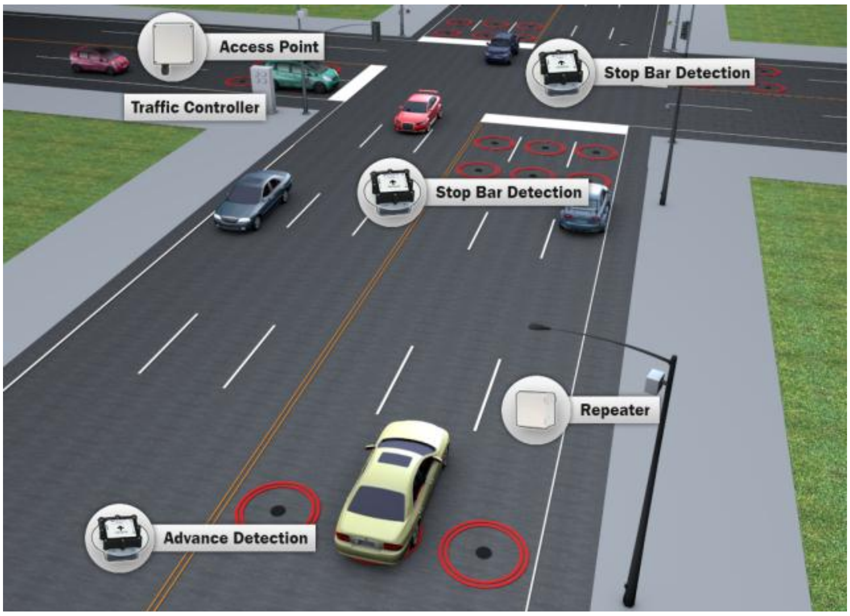

Fig. 1.6: Transportation WSN application [9].

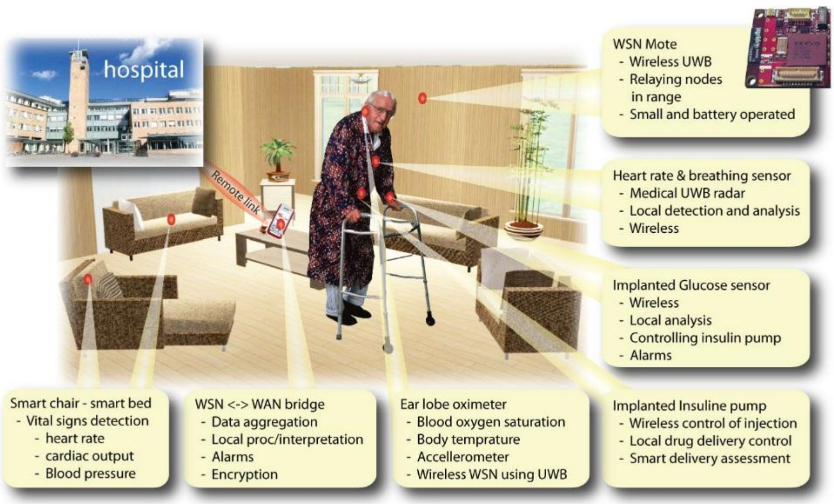

Fig. 1.7: Health WSN application [9].

centers, human physiological information tele-monitoring, and tracking and checking specialists and/or patients inside a hospital as shown in figure 1.7.

1.2 WSN Challenges

WSN has made extensive variety of challenges that are still to be addressed. In this section we list the main challenges for deploying WSNs.

1.2.1 WSN Operating Systems

A sensor node operating system ought to have the capability to offer memory and resource administration in a restricted domain. Different issues in outlining a sensor network Operating System (OS) are:

- A sensor node is fundamentally part of computing the gathered data from the nearby domain. Sensor node processes the data and controls the information according to the necessity of an application.

- OS have to provide multi-hop routing and basic user level network administration, and it should have a simple programming model.

- OS should have in-built components to control the battery power consumption. Motes can't be energized when wished because of tiny size and low price prerequisite of sensors and it have to be in a location to perform restriction on all resources utilized by every application.

Numerous operating system for sensor nodes like Contiki, TinyOS, Mantis OS, Nano-Qplus have been developed putting in mind the above design issues [13, 14, 15].

1.2.2 WSN Communication Characteristics

WSN performance relies on the goodness of wireless transmission. In any case, wireless transmission in sensor networks is known for its unforeseeable nature. Several issues are connected with communication in WSN as [16]:

- In Sensor Networks (SN), low power consumption is expected to empower long working lifespan by encouraging low duty cycle functions and local processing of signal.

- Deployed sensing successfully works against different natural impediments and consideration have to be considered that signal strength, therefore the successful wireless domain isn't decreased by different variables such as reflection, scrambling and scattering.

- Multi-hop networking might be adjusted among sensor nodes to minimize transmission range.

1.2.3 Localization

Localization of sensor is crucial issue in WSN. The sensors are distributed randomly or by hand and need to be localized. Moreover, there is no supporting framework accessible to find and oversee them when they are distributed [17] [18]. Physical position of sensors after they have been distributed is called as localization issue. Localization mechanisms for a SN have to achieve the following prerequisites [19]:

- The localization algorithm has to be decentralized because a centerlaiezd methodology needs high calculation at particular sensors to determine the position of sensors in the entire domain.

- Localization algorithms have to be tolerant to find the location of the disappointments and loss of sensors. One should be tolerant to mistake in physical estimations.

- It is appeared in [20] that the accuracy of localization advances with increase in the number of beacons. A beacon is a sensor which knows about its current position. In any case, the primary issue with expanded beacons is that the cost of them is very high while other sensor nodes are cheap. When the unknown sensor nodes have been localized by this type of nodes then the beacons get to be futile.

- Algorithms that rely on ranging data such as Signal Strength (SS) and Time of Arrival require particular equipment that is normally not equipped on sensor.

1.2.4 Security

WSNs are pron to intruders' attacks, therefore many security and intrusion detection system protocols were developed to protect WSNs [21] [22]. Following are the fundamental security prerequisites to WSN application [23] [24].

- Confidentiality is expected to be guaranteed that important information is fully secured and covered to unauthorized users. confidentiality is needed in SNs to secure data going between the network sensor nodes.

- Authentication procedures should be available to verify the member in a transmission. In SNs it is important for every sensor node to be able to confirm that the information was truly sent by an authenticated sender and not by an enemy that deceived legitimate nodes for receiving incorrect information. Wrong information can modify the way a system could be anticipated.

- Lack of integrity might bring about mistaken data. Numerous sensor applications, for example, contamination and human services checking depend on the integrity of the data to work.

1.3 WSN Simulators

Since nodes are resource restricted, normal OS, communication stacks and advance tools can't be utilized. This led to the advancement of small OS particularly intended for restrict resource network. The most famous OSs are Contiki OS and TinyOS. Both of them have tools, for example, simulator, transmission stacks, and are ported to a few equipment platform. Because of the limited resources, programming nodes is very challenging and has to be very efficient. In addition nodes are battery powered and the utilization of power has to be very high [25] [26].

A simulator is a tool that emulates a real system and is typically utilized for research. Simulator can be used in different fields including material science, biology, economics, and computer systems.

A WSN simulator mimics the radio system media and the nodes in the system. Some sensor system simulators have a definite model of the radio media including impacts of impediments between nodes, while different simulators have a more conceptual model.

At the point when utilizing simulators in research experiment, the assessment of the examination can be significantly less time consuming and data about nodes and their transmission can be measured at high level of detail. It is additionally conceivable to reiterate precisely the same experience a few times. In simulation it is additionally conceivable to control most parts of nature, for example, number of nodes, moveability, loss of packet ratio, and so on [27].

1.4 COOJA Simulator

COOJA is an adaptable java-based simulator developed for simulating SN in which sensor is running the Contiki OS. COOJA simulates SN where every node can be from a different kind; varying in on-board programming, as well as in the simulation equipment. COOJA is adaptable in that numerous functions of the simulator and can be effectively supplanted or reached out with extra usefulness.

COOJA can execute Contiki application either by running the application code designed for the PC workstation CPU, or by running code requested for the sensor

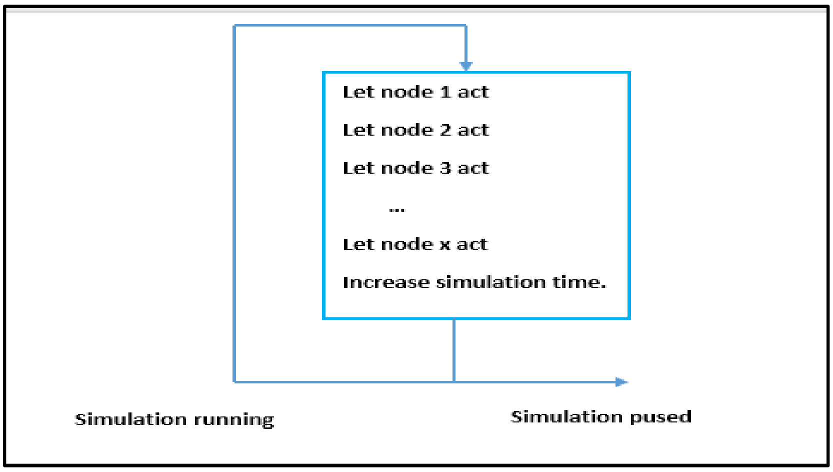

Fig. 1.8: Structure of simulation loop

node [28].

1.4.1 COOJA Design Overview

COOJA simulation comprises of various nodes being simulated. Every node is associated with a node kind. At the point when the simulation is running, the majority of the nodes get the opportunity to act. Once simulation time is updated and all nodes have acted the procedure is refined represented the simulation loop as shown in figure 1.8.

More particularly, every node has its special node memory and various interfaces. The memory comprises of one or a more memory portions, each begin with address and information. The memory portions must define all interesting and required parts of a whole simulated Contiki OS together.

The interfaces perform on the memory and simulate node device, for example, a clock or a radio transmitter. For example, if the time modifies a clock interface has to update some specific variable of time. Furthermore, time variable lives in

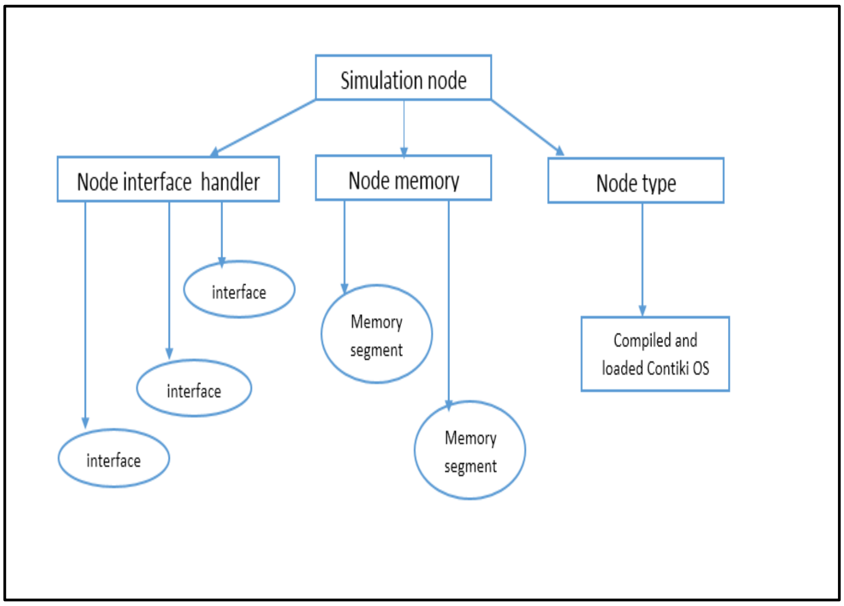

Fig. 1.9: Design of simulated node

the memory of that node.

The node kind is the extension between the node clarified above, and a stacked Contiki OS executing node specific code. This is from where the simulated Contiki OS is introduced, and the starting memory is made. And all sensors of the same kind are connected to the same stacked Contiki OS. The node kind additionally performs mapping between the variable name and address. This infers if the above clock interface needs to change the core time variable the node kind is asked what address that variable is at. At the point when a node gets the opportunity to act, the node kind is in charge of connecting the node to its related Contiki OS as shown in figure 1.9 [29].

1.4.2 COOJA Interface

COOJA interfaces [28] are the fundamental and favored approach to examine and collaborate with simulated nodes. Not only they simulate all the equipment devices, but by using the way the interfaces are treated, profoundly modified simulation conduct can be accomplished. Being entire interfaces to node devices, there might be a superior clarification that they are interfaces to node properties. For instance, one of those properties is the node position. Regularly a node does not know its actual position these kind of interfaces are called virtual. By redoing the position of interface, a simulation with moving nodes can be made. This can be of more value if one of the simulate nodes moves down the slope or moves on robot arms.

Interfaces in COOJA can be found both in the core and in the simulator. Interfaces actualized in the simulator have ability to access the node memory, and interfaces executed in the core can get access to Contiki OS functions. Regularly connections and conditions exist in the middle of core and simulator interface. For example, the radio transmitter, a radio interface must exist both in simulator and in the core. When radio information is transmitted or the interfaces communicate with one another they oppose the Contiki OS framework specifically. At the point when the node is ticked, the core interface can then convey approaching radio information by putting it away in the worldwide buffer to the Contiki OS the same route as a normal equipment device driver would do.

1.4.3 COOJA plug-in

While the COOJA interfaces are the most ideal approach to connect with simulated nodes, plug-ins are the most ideal way for a user to cooperate with a simulation. The modules are enrolled at runtime before they can be utilized, frequently when the simulator start running. The user then makes objects of the accessible enrolled modules through simulations. The plug-ins are actualized like a customary Java panel, and subsequently a user can make new progressed graphical interfaces in a straight-forward manner [28].

Plug-ins can be classified into four different types as follow [30]:

- GUI Plugin: This kind requires a running GUI to be built and this is gone as an argument when a user introduces the plug-in. In general, this plugin is elective. Nevertheless, users can get to pertinent data, for example, the present simulation and additionally simulated motes by the GUI as shown in figure 1.10. This kind of module just relies on the GUI, so there is no need to delete it when the present simulation is deleted.

- Simulating Plugin: This module relies on a simulation. The present simulation is gone as a parameters to the simulation module when it is made. The plugin need to be deleted when the simulation is deleted. At the point if another simulation is made, the plugin of simulation can be automatically made. An exceptionally helpful use of the this plugin is to show data about the present dynamic simulation, such as, the number of nodes, nodes kinds, nodes location and status of simulation.

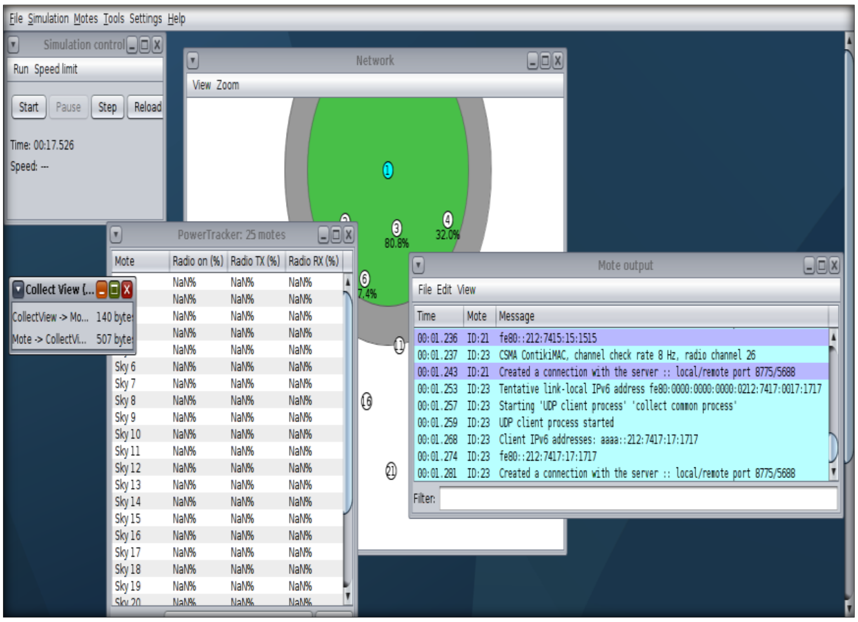

Fig. 1.10: COOJA plugins

- Node plugin: Node plugin (Mote plugin) relies on a node need to be simulated. Subsequently, if a node is deleted the plugin is additionally deleted. This plugin is helpful to screen node conduct, for instance, it can watch a creation node variable and stop the simulation in view of the predefined estimation of variable. A power use history plugin is a decent case of this kind which is extremely valuable in checking the accessible battery power of node and showcase a grave of time utilizing observed information.

- Dynamic plugin: Any type of plugin can be enrolled as dynamic plugging. COOJA support enrolling and unenrollded plugins according to the prerequisites of present simulations. By utilizing the dynamic plugin, a simulation can enroll more than one plugins of its own. Wireless medium is a good case of this kind. A bland visual interface is not generally enough since radio medium can enroll one or a few plugins of its own.

Some prominent plugins that show essential usefulness are executed in the fundamental type of COOJA. This incorporates seeing mobile nodes, checking radio traffic, observing output log and controlling simulation [30].

1.5 Motivation

The motivation driving this work is the extensive variety of utilizations for WSN localization in numerous fields like route, security and health-care. If the precision of wireless tracking is expanded, the application and the utilization of this method would be expanded and reached out to different fields of utilization. The urgent specialized issue is that present wireless localization technologies offer different resolution to allow poisoning to this level of precision. The work in this thesis will compare two major protocols of indoor localization which are range-based and range-free and present the best technology that offer acceptable accuracy and has low power consumption .

1.6 Problem Statement

Indoor localization is one of the recently developing technologies having potential for various applications in the business and open security fields. The localizing of a mobile node is the most challenging and interesting area in WSN, there is a need for algorithms to achieve high accuracy with no extra hardware. The difficulties of finding the location of a mobile node in a sensor network is drawing a huge consideration in later years. A number of issues that ought to be taken in deploying localization algorithms:

- Accuracy: Distinctive applications have diverse necessities on localization and tracking accuracy. It is vital to build tracking application that meets the required accuracy.
- Energy limitation : All nodes are powered by a limit energy source, as a result, the application should be energy-aware, especially in the communication process.
- Signal interference: In the same collision zone, only one node is granted access to the medium, which creates interference to other nodes.
- Robustness : The protocol should be stable and insensitive to temporal change.

1.7 Research Objectives

The principle point of this work is to enhance tracking efficiency as far as power utilization, and localization accuracy for tracking application based on ZigBee WSNs. The specific research objectives required to achieve the following:

- Perform a comprehensive literature survey on indoor localization protocols.
- Performance comparison between range-based and range-free localization protocols.

- Optimize the number of messages in the network to conserve power.

1.8 Methodology

- Survey the relevant work.
- Simulate the deployed algorithms using COOJA simulator.
- Deploy a multi-hop protocol and implement it using COOJA simulator.
- Compare and evaluate the performance of different WSN protocols.

1.9 Thesis Outline

The outline of this thesis is laid out as follows: Chapter 2 is explore a localization in WSN and presents the most common ranging techniques, localization algorithms and localization methods. Chapter 3 describes the Range-Based localization protocol and presents the experiments and the performance of some algorithms that belong to Range-Based protocol, such as RSSI and Fingerprint with two aspects factors the accuracy and power consumption that is followed by Chapter 4 which describes the Range-Free localization protocol and shows the experiments and the performance of some algorithms belong to Range-Free protocol, for example Centroid and DV-hop with also to the aspects and factors like the accuracy and power consumption. Finally, Chapter 5 contains conclusion and future work.

CHAPTER 2

LOCALIZATION IN WIRELESS SENSOR NETWORK

The built-in features of WSNs make the node's location an important factor in determining their state. The information related to the node location represents a vital factor for most WSN applications. In such applications, the estimated information is useless without knowing the exact position from where it was acquired. Localization can be used in many applications such as sensing, tracking, alerting, routing enhancement and traffic management. Such kind of services made WSNs valuable tool for observing characteristic phenomena, natural changes, controlling security, evaluating activity streams, checking military application and tracking friendly military forces in the front lines. These duties require a very high unwavering reliability of sensor networks [31].

In some WSN applications the nodes of the network can be set physically in altered arrangements that takes into consideration the framework to know the definite directions of every sensor. For a dynamic network where nodes can move or if nodes are set into the network without precision there must be some kind of localization strategies for the accumulated sensor information to mean anything.

Nodes can be outfitted with a Global Positioning System (GPS), yet this is an expensive arrangement as far as size, cash and power utilization are concerned. For, sensors utilized indoor are considerably not to utilize GPS as a mean of localization as it requires viewable pathway to satellites [32].

Localization indoors is frequently more complicated than outside due to the moving environment. For example, barrier, dividers, floors, roofs and furniture blocking line of sight between sensor nodes can cause large error in estimation of distances, and power consumption [33]. Common approaches in tracking an indoor localization are utilized to assess the location of nodes in the network utilizing the predefine position of couple of nodes named reference nodes or beacon nodes. Beacon nodes can get their actual locations by their arrangement at a study areas.

Beacons are utilized to assess the positions of mobile nodes either by estimations of direct distances, called a range-based method [34], or by an range- free procedure [35]. A range-free procedure would be including number of hops of the communication routing between the nodes. A localization calculation can then be connected to compute the best fit from a few estimations between various blends of nodes.

2.1 Literature Review

A huge amount of work is effectively done in the field of localization. In this section, a number of localization approaches are reviewed. Also, a work that is straightforwardly identified with this work is shown in this section. In [36], the authors concentrate on tracking the mobile node by distributing low-density sensor node. They used a new approach that improved the accuracy of mobile node location depends on weight function. The weighted approach computes the weights between the reference nodes that have predefined locations. That depends on finding the relation of distance between the beacon nodes and the received signal strength (RSS). In [37], authors used centroid location (CL) mechanism. In this mechanism, WSN should consist of a constant number of beacons nodes, and constant number of mobile sensor nodes, in which the number of beacons should be less than mobile nodes. The references or beacons nodes are equipped with GPS device to get their exact location. The CL calculates the position of the mobile nodes within two consecutive states. In the first state, the beacon nodes send their location to all mobile nodes inside their transmission area. While, in the second state, the mobile nodes calculate their position by centroid from all beacons using averaging. In [38], authors presented distribute algorithms for localization based on Gauss-Newton approach. Each sensor node gets its position by calculating the Gauss-Newton value for a neighborhood expense capacity and picking a fitting step length. At that point, it transfers the calculated value to all the neighboring sensors. Additionally, authors show that no extra cost is needed for the general work of localization. Wen-Jiang Feng [39], worked in improving the localization algorithm that depends on RSS their work endure some negligible errors in the data of device position, a reference grapple node is utilized. Moreover, Dixon strategy is utilized to uproot the exceptions of Received Signal Strength Indicator. The standard deviation edge of RSSI and the learning model is advanced to decrease the running error of RSSI and enhance the localizing accuracy adequately. IN [40], the authors compared the performance of various linear square estimation methods. The linear and non-linear squares are employed when the positioning system depends on Time of Arrival parameter to determine the location of the mobile nodes. They showed that linear square (LS) that was studied for ToA localizing produced good results. In [41], the proposed work explores the issues of object localization when an audio event happens in the sensor field. The sensor field is planned to have at least four sensor nodes per each group. Each sensor within the group is in the communication range for all group members. A lightweight audio target localization framework for WSNs on the basis of Time Difference of Arrival is introduced. At the point when an audio target is recognized, each sensor within a group of computes an approximates location of the target node. A. Boukerche used RSSI-based trilateration localization algorithm to calculate the exact position of the unknown nodes or mobile nodes [42][43]. It depends on the alterations procedure, which used the following equation of the circle:

$$d^2 = X^2 + Y^2 \tag{2.1}$$

Each circle centered by specific point at (x_1, y_1). Then, the equation can be simplified as follows:

$$d_1^2 = (X - X_1)^2 + (Y - Y_1)^2 \tag{2.2}$$

trilateration method works with three anchor nodes that have three distances d_1, d_2 and d_3 to the mobile node (blind node), the formula for the three spheres can be represented as [43]:

$$\begin{aligned} d_1^2 &= (X - X_1)^2 + (Y - Y_1)^2 \\ d_2^2 &= (X - X_2)^2 + (Y - Y_2)^2 \\ d_3^2 &= (X - X_3)^2 + (Y - Y_3)^2 \end{aligned} \tag{2.3}$$

In [43] [44], The authors explained different localization methods in detail, indicated the requirements of each algorithm and compared different techniques of localization based on cost, accuracy, energy efficiency and hardware size. The results showed that RSSI technique achieves the same goal, but with lower costs than ToA. Beside, TDoA is found to have the highest accuracy compared to the AoA, the RSSI and ToA. Moreover, they proposed a new localization method that is called Multi-Dimensional Scaling (MDS). This method calculates the location of nodes, which is in the same range of communication scope of each other . In [45], the authors explained the RSSI and fingerprint algorithms for indoor localization and they proposed Closer Tracking algorithm (CTA). CTA compounds the above two algorithms and takes their advantages to decide the position of the mobile sensors inside a house. This proposed work could be achieved by four steps, as follow: build a list of neighbors, choose a mode, adjust an assistant position and approximately closer approach. The CTA was executed by utilizing ZigBee CC2431 modules. The experimental results demonstrated that the proposed CTA could precisely focus the position with an error distance less than one meter. In the meantime, the proposed CTA has no less than 85 percent accuracy when the distance is less than one meter. Researchers in [46], proposed localization algorithm for an object rely on the last square algorithm and DV-Hop algorithm using WSN, where the DV-Hop is presented by unknown reference node and the information of beacon is pre-organized by mobile reference node. Also, its position information is broadcast in order to shape numerous virtual reference points.

2.2 Localization Techniques

Localization approaches can be grouped into two different classifications: Indoor and outdoor localization. The following sections briefly discuss both localization categories.

2.2.1 Global Positioning System

GPS is right now the most far reaching outside situating system, and it is taking into account an arrangement of satellites that offer three dimensional situation with precision of around three meters [47]. The GPS is a space-based radio-route framework comprising of a star grouping of satellites, a network of ground stations, and collectors. At least 24 GPS satellites circle the earth giving clients exact data on position, speed, and time anyplace on the planet. There are no less than five control stations observing the satellites. These control stations persistently track satellites and redesign the positions of every satellite. Without control stations, the exactness of the framework would reduce in a matter of days. The GPS is worked and kept up by the department of defense. With a specific end goal to get to this framework, you are required to have a GPS device. The working of GPS needs three components as shown in figure 2.1 [48]:

- Satellites: rotate around the earth.
- Base Stations (BS): these BS is located on the earth which monitors the processing on earth.
- A GPS receiver: is a device that is capable of receiving information from GPS satellite.

Utilizing the times stamp, data sent by the satellite, the GPS recipient compute the time taken by the signal to fly out from the satellite to itself. By utilizing this travel time data, the GPS recipient computes the distance to each of the satellites.

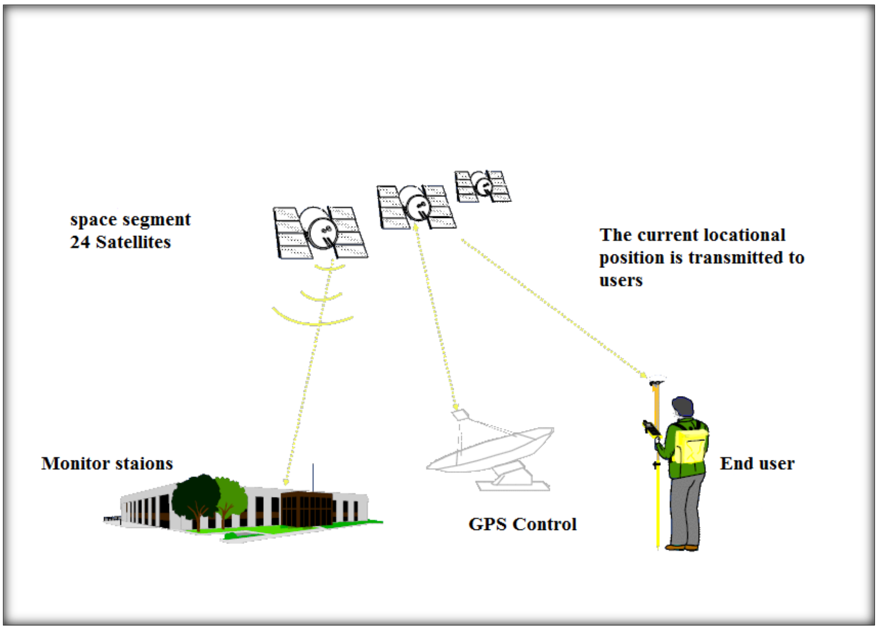

Fig. 2.1: GPS Components

Finally, utilizing these computed distances, geometric trilateration is utilized to find out the position of the GPS recipient.

2.3 Indoor Localization

In general, an indoor localization system is a system that can decide the location of mobile target in physical space such as in a hotel, hospital, school and tunnel. Indoor localization approaches use range assessments to decide the estimated location. The localization processes of indoor localization are shown in figure 2.2 [49].

The procedure for acquiring a location measure includes diverse levels of complexities. At the beginning, the mobile target (MT) gets a signal from reference nodes or anchors. In the context of traditional localization an mobile target

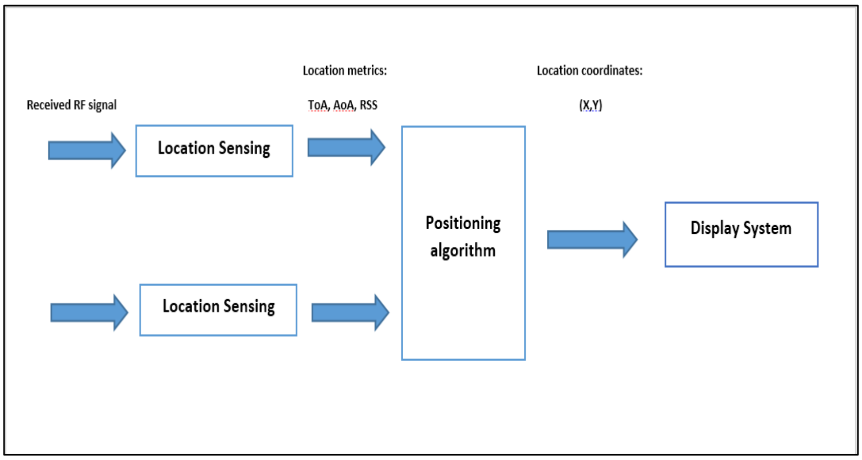

Fig. 2.2: Indoor localization process

listens to ranging signals from no less than three distinct reference nodes, for 2-dimensional position.

In WSNs collaboration localization mobile targets are typically indicated as blind nodes, while reference nodes are indicated to as anchors.

In RSS frameworks, for example, the overall signal power that a mobile target gets from an anchor can be utilized to assessment the distance. For a given received power, it is conceivable to estimate the relating distance with some confidence. The RSS procedure is typically easy to execute, however experiences errors, particularly in multi-path rich domain. Moreover, for ToA based framework the distance is evaluated by sending a RF signal and recording the time it takes to get that signal. This methodology is more precise duet to the fact that the arrival time is agree with the straight path distance.

Once three range estimations are received from various anchors, the mobile target passes the measurement data (RSS or ToA) to a positioning approach, where the positioning system process the received data using some positioning algorithms to obtain the position(coordinates) of the mobile target, finally, the final coordinations (x,y) is forwarded to the display system. Figure 2.2 demonstrates an illustration of 2-dimensional localization, where a mobile node has three rang estimations to various anchors. The error of positioning, influenced by the precision of the range estimation and the number of anchors and their relative geometry to the sensor node. In the following section we discuss the most used indoor localization techniques.

2.3.1 Received Signal Strength Indication (RSSI)

The main characteristic of radio propagation is that the signal strength attenuates as the distance among sender and receiver increments. The power of the signal decreases exponentially as the distance increases and receiver can determine this attenuation based on RSSI in order to measure the distance to the sender. Receiver measures the power of the signal based on RSSI. Based on the transmitter power the propagation model and propagation loss are determined and they can be mapped into distance measurements. RSSI method is used mainly for RF signals. One common way to acquire a distance is to depend on determining the RSSI of the incoming messages. The thought behind RSS is that the designed transmission power at the transmitting node (PTX) straight forwardly influences the accepting power at the getting node (PRX). In principle, a power relation between a romanticized transmitting sensor and an accepting sensor node carries on

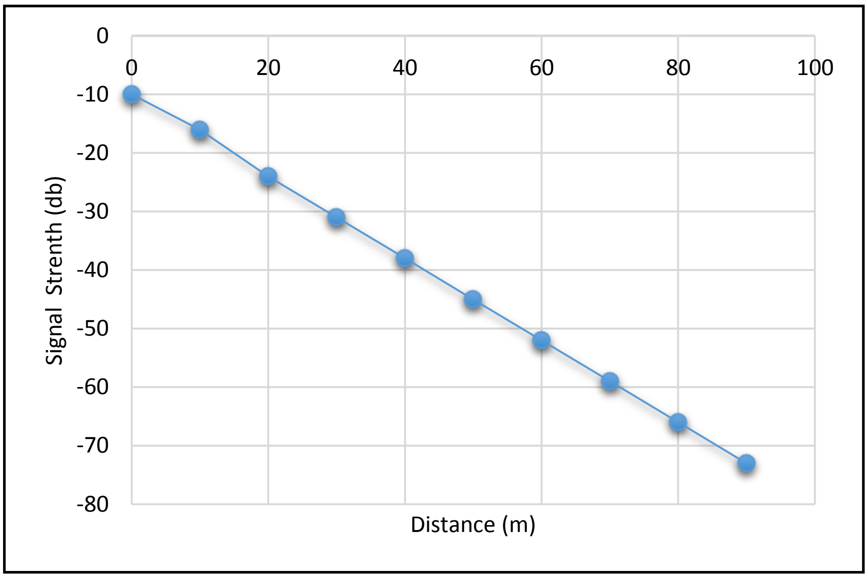

Fig. 2.3: Relationship between RSSI and distance.

quadratically to a distance. The RSS values are decreases as the distance increase as shown in figure 2.3. Well known as Friis transmission equation represents the direct affect of transmission power to received power [37].

$$P_{RX} = P_{TX} * G_{TX} * G_{RX} \left(\frac{K}{4\pi d} \right)^2 \tag{2.4}$$

P_{TX}*: Transmission power of sender.*

P_{RX}*: Remaining power of wave at receiver*

P_{GTX}*: Gain of transmitter*

P_{GRX}*: Gain of receiver*

K*: Wave length*

d*: Distance between transmitter and receiver*

In any case, in actuality, perfect environment conditions are not met due to impedance, obstacles, flection, reflections, in homogeneities of materials, and loose estimation strategies. Frameworks depending on RSSI as information parameters, if broad post handling is utilized have a tendency to be entirely exact for short ranges , but are loose if passed a couple meters. At short ranges, distance estimations with 2 meters arrived at the midpoint of localization error at the most extreme scope of around 20 meters [50].

2.3.2 Time of Arrival (ToA)

ToA approach depends on time of signal travelling to estimated distance between a mobile node and beacon node. Ordinarily, ultrasound signals are conveyed in the ToA based localization frameworks, as appeared in figure 2.4.

ToA is a generally utilized technology to perform localization. It is for instance utilized as a part of radar frameworks. The fundamental ToA algorithm depicts the anchor nodes and the mobile node, co-working to measure distances by utilizing timing results. The mobile node will send a message to each of the beacon nodes to determine the distance. The moment the mobile node transmits a message, it represent a time stamp (t_1), demonstrating the check time in the mobile node towards the beginning of the message transmission. At incoming of the message at the beacon node, the check time in the beacon node is put away as time-stamp (t_2). The distinction between time-stamps (t_1) and (t_2) demonstrates the time required for the signal to go from the mobile to the beacon node through the air [51].

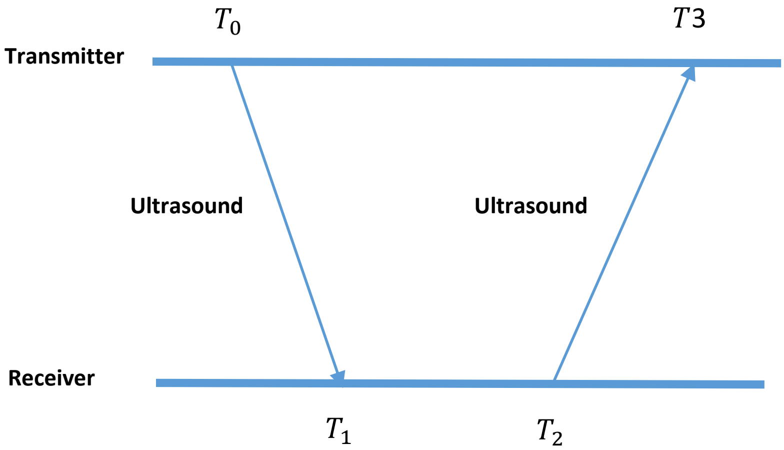

Fig. 2.4: Time of arrival protocol

ToA localization incorporates measuring the ToA from no less than three beacon nodes, and after that triangulates the objectives position. ToA frameworks need a high accuracy clock in the connection system. The distance d between every beacon node and mobile node can be calculated using the following.

$$d = \frac{((T_3 - T_0) - (T_2 - T_1)) * \nu}{2} \tag{2.5}$$

Where, T_0, T_1, T_2, T_3, *and* v *a*re the time instances and velocity of ultrasound signals respectively [52].

2.3.3 Time Difference of Arrival (TDoA)

Time difference of arrival calculates the distance depending on two radio signals going at different speeds, for example, radio frequency and ultrasound. The dis-

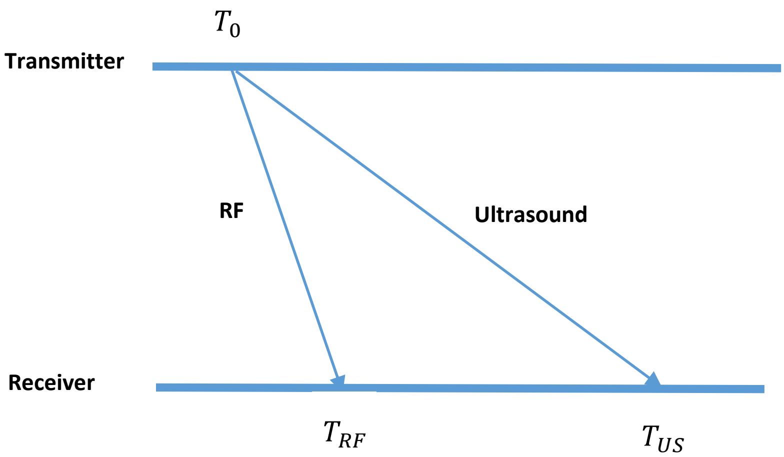

Fig. 2.5: Time difference of arrival protocol

tance between two nodes can be determined by determining the difference between the transferring time and the arriving time [52, 53]. As portrayed in figure 2.5. The distance d between the transmitter and recipient can be computed utilizing equation 2.6:

$$d = (T_{US} - T_{RF}) * (\frac{V_{RF} * V_{US}}{V_{RF} - V_{US}}) \tag{2.6}$$

T_{US} : *Time of Ultrasound signal*

T_{RF} : *Time of Radio frequency*

V_{US} : *Velocity of ultrasound signal*

V_{RF} : *Velocity of radio frequency*

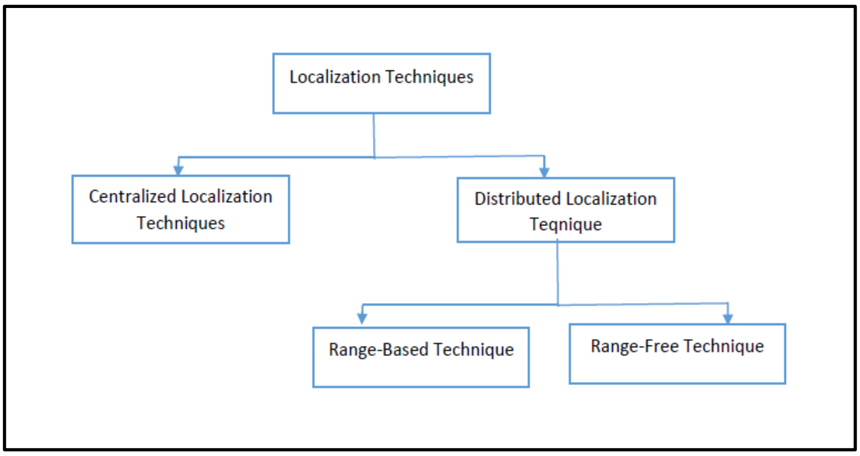

Fig. 2.6: Localization taxonomy

2.4 Localization Taxonomy

Numerous localization methods have been recommended to give location data of nodes. The localization protocols are classified based on different aspects, with regard to computation method, the localization strategies can be extensively classified into centralized and decentralized or distributed systems as shown in figure 2.6.

2.4.1 Centralized Localization

Centralized localization requires the localizations transmission data to a central node with a specific end goal to compute the mobile node location asshown in figure 2.7. Transmitting the localization data of the mobile node to a central PC is fairly expensive due to the fact that the power supply for every node is constrained, and the long-range multi-hop information transmission is expensive and normally wasteful. Therefore, the constrained power supply accessible at every sensor node

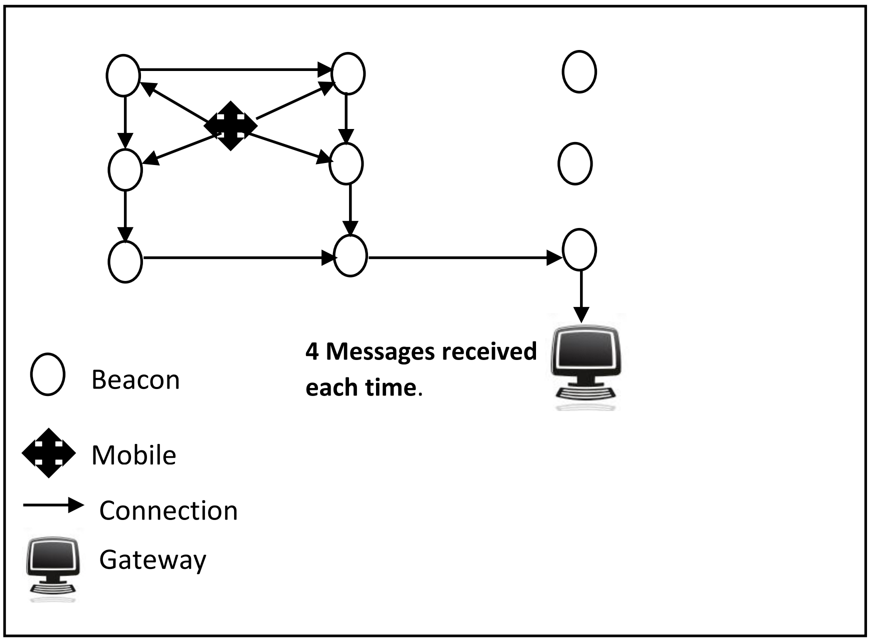

Fig. 2.7: Centralized localization

implies that any connection with a facility of centralized computing is costly. Besides, sending time arrangement information inside of the network presents latency, and in addition expending energy and network data transfer capacity [52].

The disadvantage of this approach is absence of ability to get information in legitimate path and in addition lack of scaling. It is more open for little scale systems. In light of presence of worldwide data, it is more exact than other algorithm. The prevalent centralized localization algorithms are: Multi Dimensional Scaling-Mobile Assisted Programming (MDSMAP), Semi Definite Programming (SDP), Simulated Annealing based Localization (LBSA) [54].

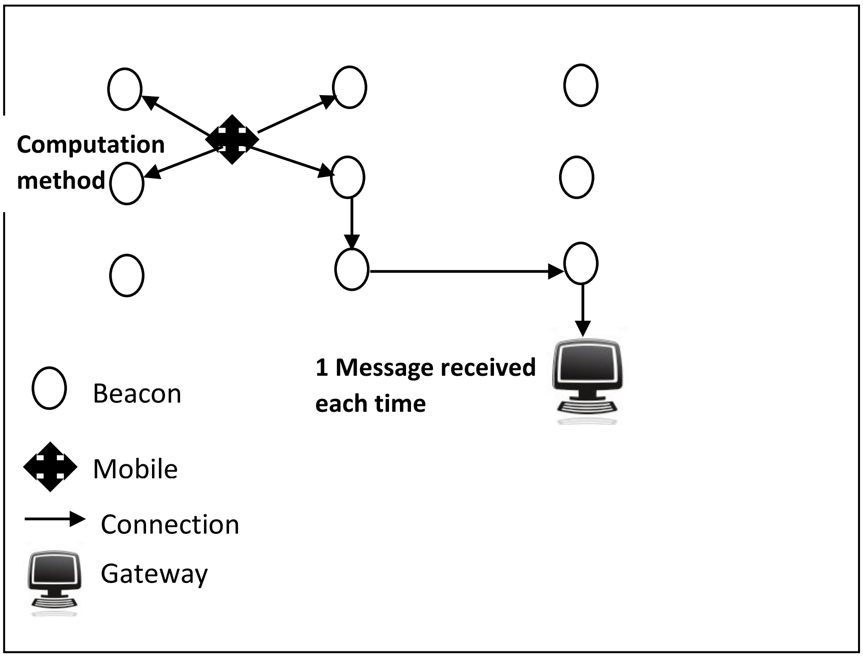

Fig. 2.8: Decentralized localization

2.4.2 Decentralized Localization

Decentralized localization methodologies require less connection between sensors nodes and subsequently decreases WSN power consumption as shown in figure 2.8. On the other hand, decentralized localization frameworks need equipment to be joined to every portable target to acquire the localization data from references nodes, calculate its position, and transfer its present position to a central PC [52].

2.5 Localization Methods

Numerous localization approaches have been proposed to give position data of nodes. In this section we discuss the concept of two different localization methods which are trilateration and fingerprint.

2.5.1 Trilateration

The localization in wireless networks is a procedure of position determination in the entire zone or just in a characterized part. The consequence of the localization procedure is the evaluated position or zone, which are received by utilizing a specific localization system.

The trilateration strategy depends on information of reference point positions and the separations to them. The trilateration technique utilizes parameters of known networks such as a recurrence of signal, its signal quality and genuine directions of access focuses in the location. The signal quality got by mobile target can be utilized for separation estimation between the AP and the blind node. By utilizing this technique one considers three or more reference nodes distributed in the building. The RSS in these focuses diminish exponentially relying upon separation in the middle of transmitter and collector and irregular clamor component. Along these lines this reliance can be considered as capacity of separation. The separation assessed by RSS is introduced as a circle around an center point. The convergence of three beacons sweeps gives a point or a range of beneficiary.

This model can be appeared in mathematical statement framework as in equation 2.7.

$$d_1^2 = (X - X_1)^2 + (Y - Y_1)^2$$
$$d_2^2 = (X - X_2)^2 + (Y - Y_2)^2 \quad (2.7)$$
$$d_3^2 = (X - X_3)^2 + (Y - Y_3)^2$$

The solution of this equation gives points of circles intersection providing an area of indoor localization as figure 2.9:

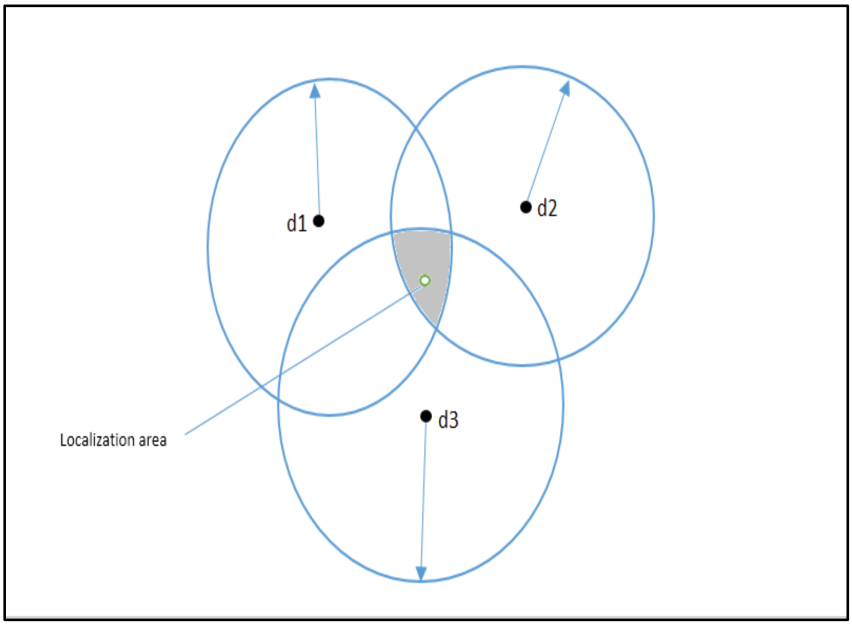

Fig. 2.9: Trilateration method

The trilateration approach for the most part comprises of two stages: **the initial step**, changing over RSS to evaluated distance by some estimation strategy (it might be flag proliferation model for indoor WLAN signals); **the second step**, processing location by utilizing assessed distances. Likewise, it is important to decide a rough sweep with same estimations of RSS for each reference point. This issue requires the signal forecast model building. Way loss of radio signal is the biggest and most variable amount of additions and misfortunes from the transmitter to the collector. It relies on upon recurrence, receiving wire introduction, entrance misfortunes through dividers and floors, the impact of multi-path proliferation, the obstruction from different signs, among numerous different elements [55]. Relying on this downside trilateration methodologies one could give worthy precision inside the room.

2.5.2 Fingerprint

The fingerprint localization system depends on the conduct of signal propagation and data through the tracking geometry field, which is separated into various smaller grids. Location fingerprint is operated by deciding how the signals will carry on at each framework point (grid point), i.e. each edge of every network.

Deployment of fingerprint localization system is generally isolated into two stages, as appeared in figure 2.10. To begin with, the offline stage: involves measuring the location for a mobile node in distinctive coordinate, and saving the gathered data in a Database (DB). Then, the on-line stage: the mobile node gathers a few RSS values from distinctive beacon nodes in its area and sends it to a server. The server applies an on-line seeking calculation to determine the mobile objects location.

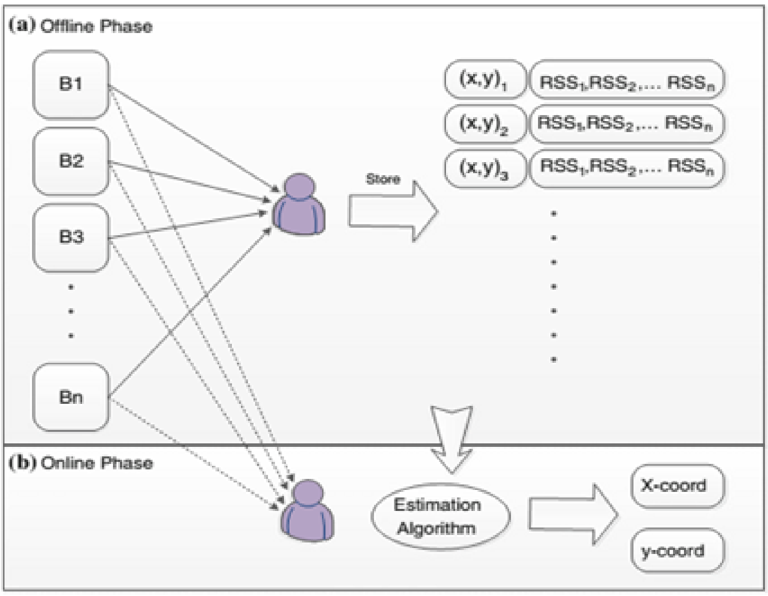

Fig. 2.10: Fingerprint method [52].

CHAPTER 3

RANGE-BASED LOCALIZATION PROTOCOL

3.1 Localization Based on RSS

This mechanism is proposed to define the location of the mobile node in an indoor environment. This is done depending on calculating the environment factors using RSS. This technique computes the environment factors between the references nodes with predefined coordination, evaluate the relation between the RSS and the fixed distance among beacon nodes.The proposed work can be divided into four consecutive stages as depicted in figure 3.1

3.1.1 Initial Stage

The operations of this stage are fixed and are done before starting the localization process. It aims to calculate the environment factors between the beacon nodes.

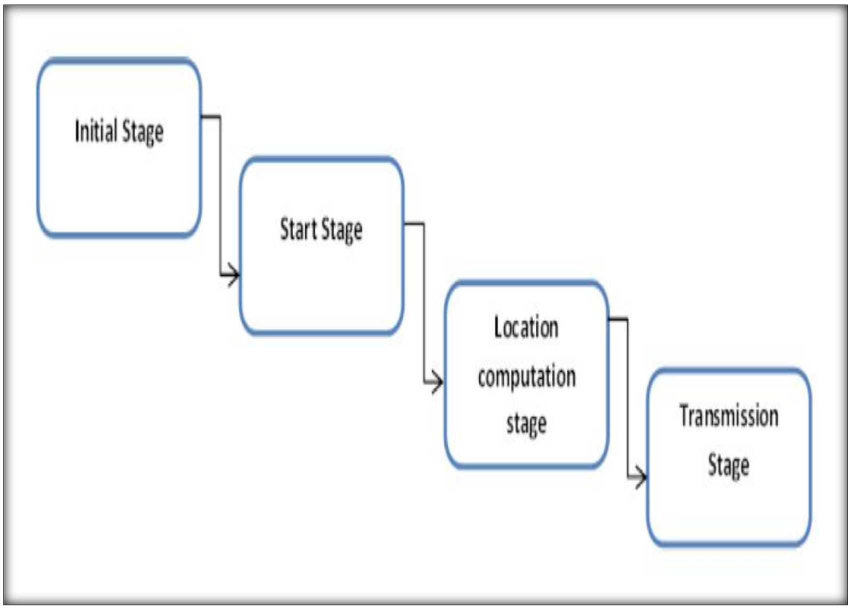

Fig. 3.1: RSS localization stages

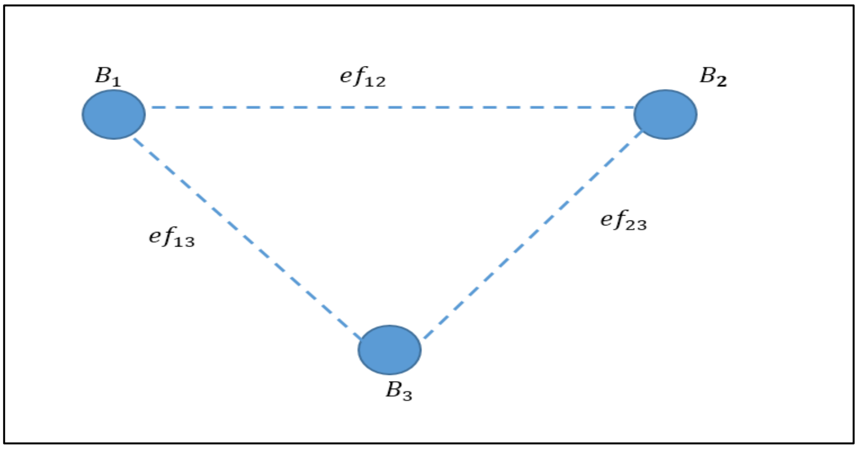

Fig. 3.2: RSS initial stage

The anchor nodes are distributed in the study area with a known and fixed distance between them i.e. the RSS are measured between the beacon nodes as shown in figure 3.2

The environment factor can be computed depending on the distance among the reference nodes and the RSS value. The distance (d) is fixed between the

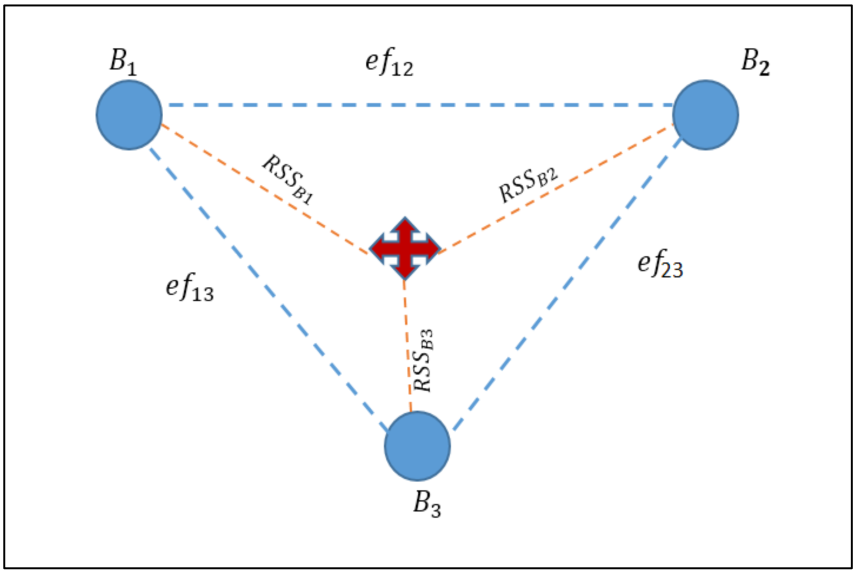

Fig. 3.3: RSS start stage

beacon nodes, and the RSS values (rss) between the beacon nodes is measured. Accordingly, the environment factors (ef) can be calculated using equation 3.1:

$$ef = \frac{rss(b_i, b_j)}{d(b_i, b_j)} \tag{3.1}$$

$rss(b_i, b_j)$: *indicates the RSS value between the beacon* b_i *and beacon* b_j , $d(b_i, b_j)$: *indicates the distance between the beacon* b_i *and beacon* b_j

3.1.2 Start Stage

In this stage, target mobiles enter the study area and start sending the broadcast messages to all beacons in its communication range as shown in figure 3.3.

Each beacon node receives a broadcast message sends a reply response message to the target mobile. The target mobile node measures the RSS values based on the reply message of the beacon nodes and stores this value in a temporary storage.

The mobile node checks the temporary storage only if there are at least three RSS values based on the reply message of the beacon nodes and stores this value in a temporary storage. The mobile node checks the temporary storage only if there are at least three RSS value from three different beacon nodes, otherwise, it will re-broadcast the messages because the trilateration method that will process in next step requires the mobile node to be surrounded by at least three beacon nodes.

3.1.3 Location Computation Stage

This stage is responsible for computing the location of the target mobile. A decentralized protocol is proposed in order to get an efficient energy consumption so that each mobile node is responsible for computing its location. The process of computing the mobile location requires two steps. The first step includes determining the distance between the mobile node and beacons. The next step includes the trilateration process. For distance determination, after the mobile node receives the reply messages from at least three beacon nodes in start stage, and the environment factor between the beacon nodes, which was calculated in the initial step, each beacon node is then covered by two environment factors as shown in figure 3.4

The distance is computed by the equation equation 3.2.

$$D = \frac{\frac{rss(M_t,b_i)}{ef_{ij}} + \frac{rss(M_t,b_j)}{ef_{(ij+1)or(-1)}}}{2} \tag{3.2}$$

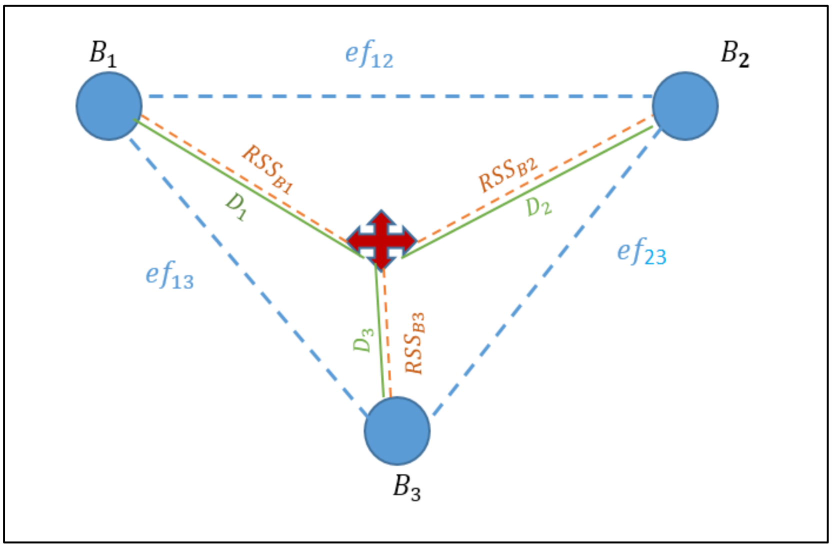

Fig. 3.4: RSS location computation stage

Where D indicate the distance between the mobile target and beacon b_i, ef_{ij} denotes the environment factor between beacon i and j .

After calculating the distance, the trilateration can be done using the circle equations for three distances as shown in equation 3.3 :

$$\begin{aligned} d_1^2 &= (X - X_1)^2 + (Y - Y_1)^2 \\ d_2^2 &= (X - X_2)^2 + (Y - Y_2)^2 \\ d_3^2 &= (X - X_3)^2 + (Y - Y_3)^2 \end{aligned} \tag{3.3}$$

At the end of this step, the coordination (X,Y) of the mobile target have been estimated.

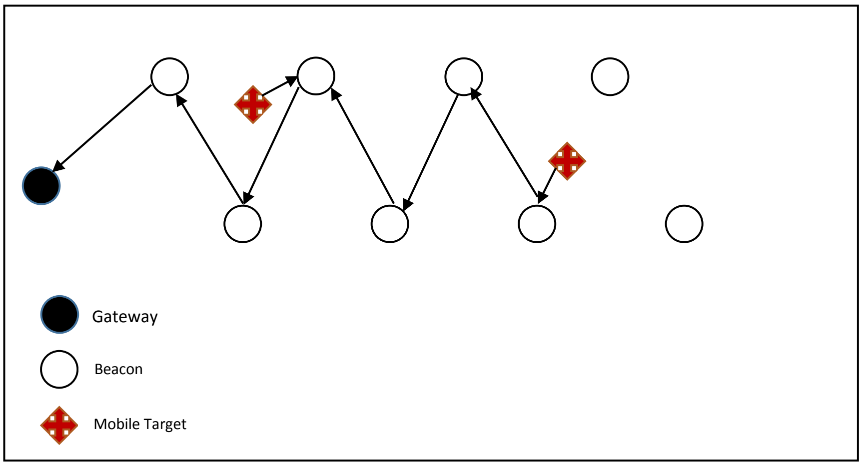

Fig. 3.5: RSS transmission stage

3.1.4 Transmission Stage

The final coordination information of the mobile target node specified using the previous stages is sent to the sink (gateway) as shown in figure 3.5.

This is done decentralized in order to conserve the power consumption. The multi-hop protocol is used to transmit the location of the mobile target from its current location to the sink node over the path of beacon nodes. The path is determined by the mobile node by sending the location information to the nearest beacon and the nearest beacon then sends it to its neighbor until it reaches to the sink (gateway). The final result is then displayed in the SINK node.

3.1.5 RSS Work Flow

The work flow is represented in figure 3.6. The figure shows all steps of RSS protocol. At the initial stage the environment factor is computed. Followed by start stage where the mobile checks the number of messages received from beacons,

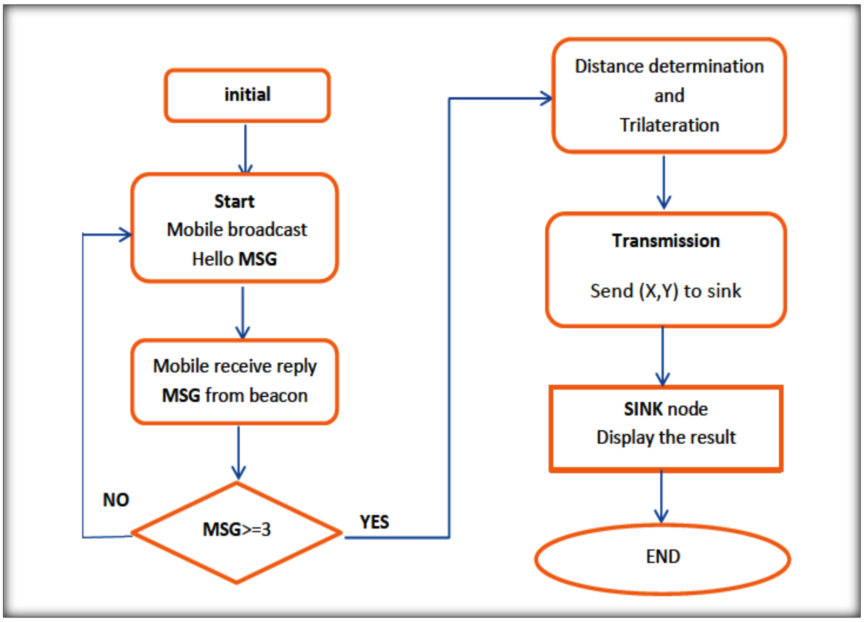

Fig. 3.6: RSS work flow

if they are greater than or equal to three messages, it forwards RSSIs message to next stage. Otherwise the mobile rebroadcasts another message. Finally, at the transmission stage the current position of the mobile is sent to the sink, in which the sink node is collects and presents the results.

3.1.6 RSS Simulation Results

RSS Topology Network

The topology used in our work is triangle topology. We used this topology to conserve the power by reducing the transmission range of mobile, also to minimize the number of beacons.

In this network topology, the anchor (beacon) nodes are deployed in two different horizontal lines at which each anchor is connected with only the previous and next nodes in the opposite line i.e., no nodes in the same line is connected as presented in figure 3.7.

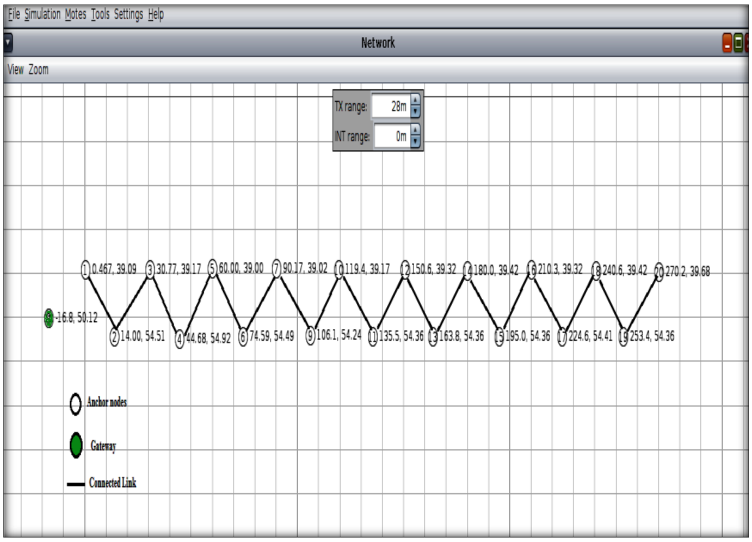

Fig. 3.7: Network topology

In figure 3.7, the anchors distributed in horizontal lines so that node with ID 1 communicated only with a node with ID 2 because it is in the edge of the topology and it is the node that makes the connection to sink node (Gateway). A node with ID 2 connected with two nodes because it is in the middle of the topology; the previous and next. Node 1 (previous), node 3 (next) and the other nodes are connected in a similar manner with previous node and next node for the node in the middle of topology and with one node at the edge of topology. The gateway node is the one that is connected with node 1 only.

All other nodes send the final result to the gateway using multi-hop WSN which is a network that its devices are connected using wireless communication. Due to the limitation of the wireless communication range, some nodes cant communicate directly to each other. However, they forward their data to each other using many intermediate nodes. A source sensor sends data to its neighbor and the neighbor transmits it to one of its neighbor and so on until the data is transmitted to the final destination.

The Simulation Platform

COOJA is a new sensor network simulator for the Contiki OS. The Contiki OS is a portable OS design for restricted resource devices, for example, sensor node. It is constructed around event driven kernel; however, it supporting multi-threading. Likewise, it supports full TCP/IP stack by means of uIP and programming protothreads.

The principle outlined objective of COOJA is extendibility for which interface and plug-ins are utilized. Where interface represents the devices or mote, while the plug-in is used to interact with the simulator such as to control the speed of simulation or watch network traffic between nodes as shown in figure 3.8.

The movement pattern of mobile nodes and how their location change overtime is described by the mobile model. in our work the random model is used in which the mobile nodes change their location periodically in random manner.

The sensor devices are utilized, as a part of our work is the Tmote sky. Tmote Sky is wire sensor module that has numerous capabilities to offer like high information rate sensor system applications requiring ultra-low power. Some different components to pay special mind are high unwavering quality and simplicity of advancement. It is generally demonstrated stage for remote sensor frameworks organizations.

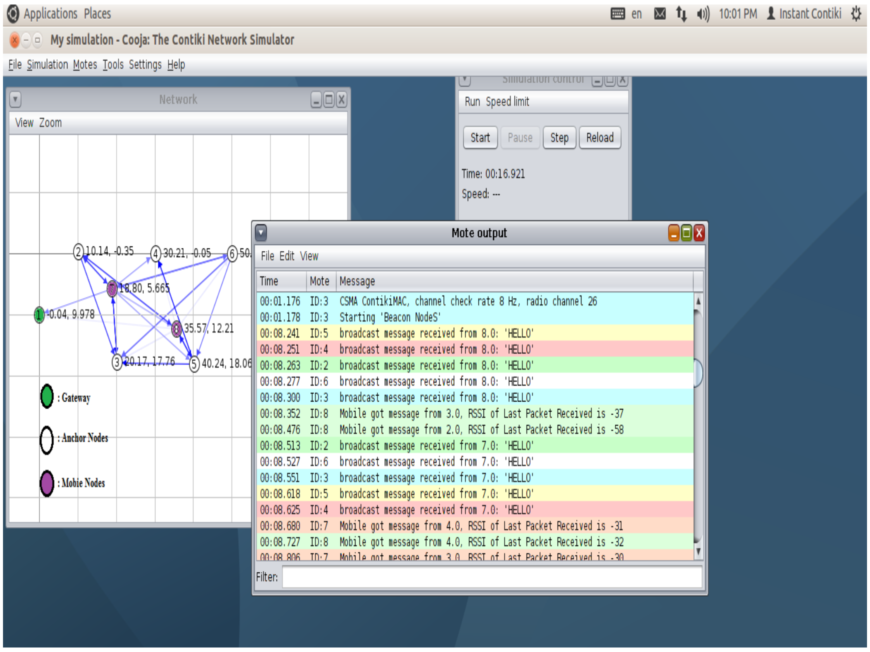

Fig. 3.8: COOJA simulation platform

The network deployment area for RSS localization system is 90 $\times$ 17 meters with 20 nodes. The distribution is 8 anchor devices and 12 unknown devices and the unknown devices can be tested in many points inside the study area.

The percentage of the beacon is 40% and the wireless communication range is 28 metres. We start to analyze the relationship between the RSS values and the distance in an indoor environment. The mobile target node gathers the RSS values from different beacon nodes in the study area. The anchor nodes are deployed in different locations and RSS values between the beacons and mobile node are collected in several points. It is known that the RSS is inversely proportional to distance. To analyze the processes of localization in RSS system, the COOJA simulator is run and all the steps of the proposed work are performed by COOJA simulator. Starting by sending the HELLO messages by mobile node then representing the second step of sending the reply from beacon node to mobile. Moreover, the mobile measure the RSS values and convert it to distance using environment factor calculated between the beacons.

Finally, the estimated location of mobile node is calculated using trilateration. The location information is sent to gateway node using multi-hop wireless sensor network. All these processes are repeated by all mobile nodes until they are localized.

3.1.7 Performance Evaluation

1. **The Accuracy**

   The RSS localization system is evaluated by analyzing the error of the calculated location. To grasp the accuracy of this system, we computed the location error between the exact coordination of mobile node and the estimated location using the equation 3.4:

$$Error = \sqrt{(X_{exact} - X_{est.})^2 + (Y_{exact} - Y_{est.})^2}. \tag{3.4}$$

   Table 3.1 contains the node ID, exact coordination of all unknown nodes and the estimated coordination of unknown nodes that were computed by RSS localization system. Table 3.1 also shows that RSS localization accuracy range is between 0.4346 meters for the best case and 2.44233 meters for the worst case. The other values are in the same range of one meter, the results showed in table 3.1 are represented in figure 3.8. The accuracy depends

Table 3.1: The accuracy of RSS system

Times (S)	Exact Coordination		Estimated Coordination		Error
	X	Y	X	Y	
1	12.9	4.2	14	3	1.62788
2	20.05	11	21	9	2.44233
3	29.58	15	29	14	1.06230
4	33.9	4.1	35	4	1.10887
5	46.48	5.8	45	5	1.67764
6	40.07	10	41	9	1.39517
7	28.45	3.6	27	4	1.50416
8	18.83	1.6	19	2	0.43462
9	13.72	12	15	11	1.58808
10	30.5	13	29	12	1.63082
AVG					1.447191

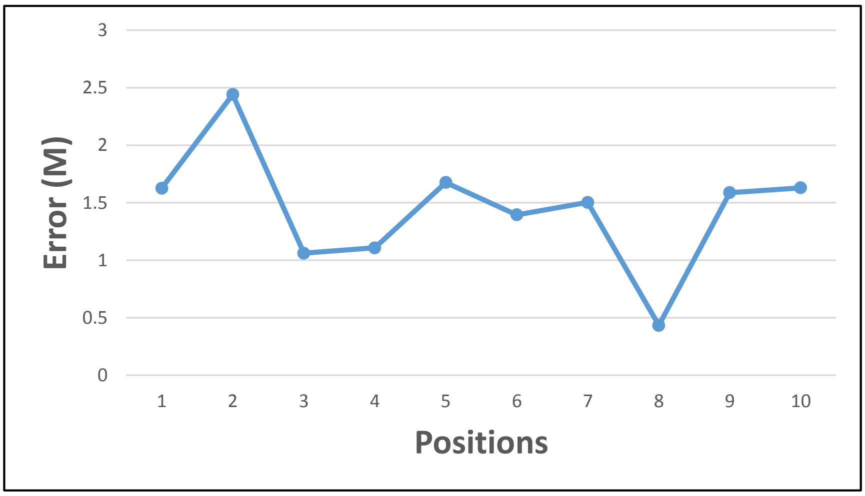

Fig. 3.9: Accuracy of RSS protocol

on the distance i.e., the more accurate the distance the more accurate the coordination.

2. **Power Consumption**

To estimate the power consumption of the RSS system we can use the PowerTrace plug-in of COOJA simulator. By checking the number of ticks per seconds for rtimer for the followings state: CPU, Low Power Mode (LPM), Transmission (Tx)

Table 3.2: Raw data of RSS system (Ticks)

Times	CPU	LPM	TX	LX
2	2383	63120	0	390
4	5572	125462	0	806
6	8764	187802	0	1222
8	16683	245554	1869	1816
10	26565	301061	4148	4548
12	29906	363251	4148	4964
14	33184	425505	4148	5380
16	47583	542169	6202	6158
18	50893	604391	6202	6952
20	54173	666643	6202	7368

and Listening (Lx).

The collected data is appeared in table 3.2. From the raw data presented in table 3.2 , we calculated the power consumption of the mobile node at any time by using equation 3.5:

$$Power(mW) = \frac{(rd_2 - rd_1) * current * Voltage}{RTIMER} \tag{3.5}$$

Where rd_1, rd_2 are the two sequence values from the raw data, Current and Voltage are the values of the current and voltage for TmoteSky sensor (from DataSheet) and the RTIMER is the number of ticks per second (presented in Contiki OS).
The values of the current and voltage it read from the data sheet of the TmoteSky for each state the constant value of RTIMER in Contiki OS is 32768 ticks per second.

Table 3.3 provides the power consumption of RSS system, it contains the power consumption of CPU, LPM, Tx, LX and Total. Figure 3.9 presents the power consumption for RSS system. It shows that the transmissions (Tx) reach the

Table 3.3: Power consumption of RSS system (mW)

Times	CPU	LPM	TX	LX	Total
2	0.262766	0.155532	0	0.337061	0.755358
4	0.263013	0.155527	0	0.337061	0.7556
6	0.652505	0.14408	1.796677	0.481284	3.074546
8	0.814252	0.13848	2.190811	2.21358	5.357123
10	0.27529	0.155152	0	0.337061	0.767503
12	0.270099	0.155312	0	0.337061	0.762471
14	1.186441	0.291055	1.974518	0.630368	4.082382
16	0.272736	0.155232	0	0.643332	1.0713
18	0.270264	0.155307	0	0.337061	0.762631
20	1.186935	0.291032	1.987976	0.337061	3.803004

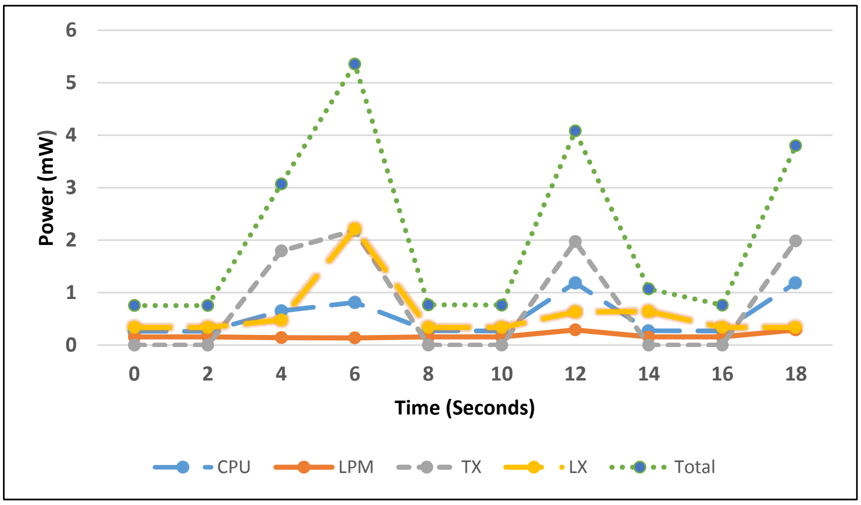

Fig. 3.10: RSS power consumption

peak value at 6 and 12 seconds, because the mobile node reply the anchor nodes that request to measure the RSS of the mobile to anchor nodes while the listening (Lx) reach the peak value at 6 and 12 seconds because it is the time of mobile node to move from one position to another position. Low Power Mode(LPM) is almost with constant value.

The duty cycle can be calculated from the raw data in table 3.2 using equation

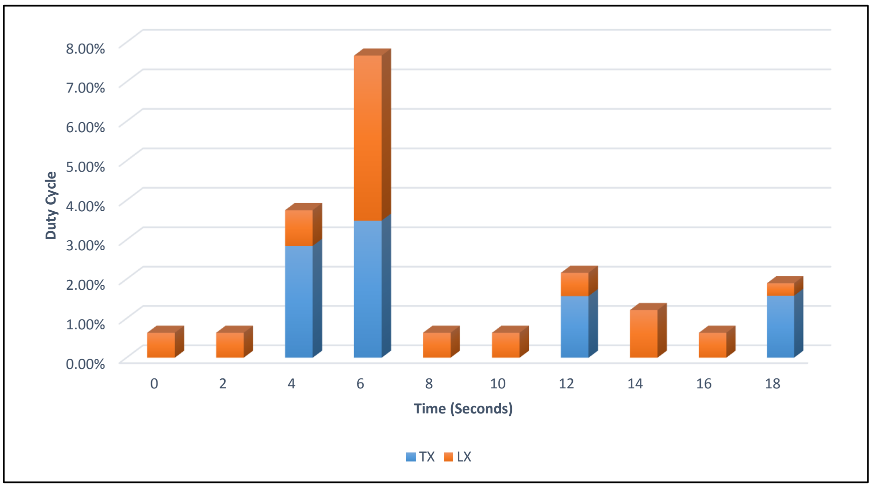

Fig. 3.11: RSS duty cycle.

3.6:

$$DutyCycle(\%) = \frac{(d_2 - d_1)_{T_x}}{(d_2 - d_1)_{CPU} + (d_2 - d_1)_{LPM}} \tag{3.6}$$

Figure 3.10 presents the duty cycle of the Transmission and Listening status. It shows the duty cycle as percentage or ratio between pulse duration of one state (Tx or Lx)and the total period (CPU and LPM) and represents the time it takes for a system to change from one status to another (Tx status to Lx status).

3.2 Localization Based on Fingerprint

A fingerprinting localization approach is introduced in this section keeping in mind the end goal is to reduce the localization error accomplished in the trilateration based methodologies. Fingerprinting localization strategy is the most encouraging technique, because of their minimal effort and high exactness regarding localization . However, fingerprinting strategy requires the accumulation of a substantial number of reference points in the tracking range to accomplish sensible localiza-

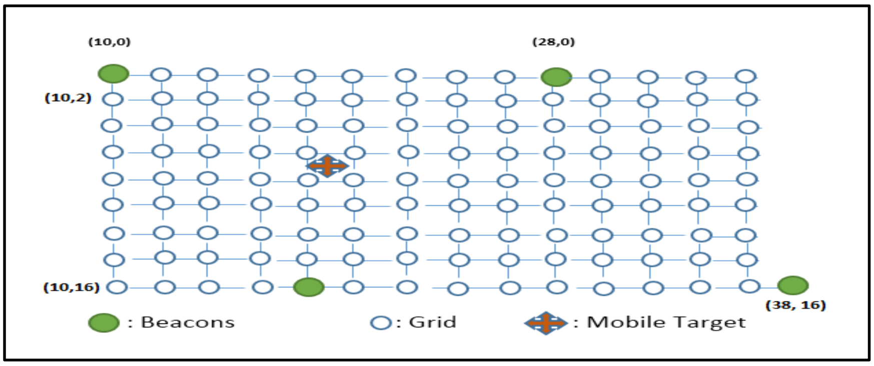

Fig. 3.12: Fingerprint localization approach

tion precision. There are two fundamental difficulties to build up a fingerprinting framework. Firstly, there is an issue of gathering the RSS values and putting away them in the database, as this procedure requires a large of of time when the interest localization area is large. Furthermore, seeking strategy through the values stored in database to figure the location is troublesome. In this section, a fingerprinting based localization methodology is proposed. This method diminishes the aggregate number of reference nodes, which needs to gather the offline stage while accomplishing low localization error of somewhere between 1 and 3.5 m. An indoor fingerprinting can be incorporated into three principle stages: the creation of the fingerprint database, the feature identification stage, and the estimation stage. The initial two stages are executed in offline phase while the third one is performed in online phase.

3.2.1 Stage 1: Fingerprint Database Creation

This phase start by dividing the study area into grid points as shown in figure 3.11, and each grid point has its own coordinate P= (X,Y). this phase contains

Table 3.4: Fingerprint database

Grid No.	Coordinates		RSS from	RSS from	RSS fom	Subarea
	X	Y	B_i	B_j	B_k	Identifier
1	X_1	Y_1	rss_{bi1}	rss_{bj1}	rss_{bk1}	A_1
.	.	.	.	.	.	.
.	.	.	.	.	.	.
.	.	.	.	.	.	.
N	X_n	Y_n	rss_{bin}	rss_{bjn}	rss_{bkn}	A_n

two steps:

1. for each grid point collect the RSS values from the three beacons $\{b_1, b_2, b_3\}$ in its transmission range and store them in database.

2. For each subarea, the number of grid points for each sub-area and the rang of each sub-area is determined based on the collected RSS values.

In the first step, manually, the mobile target goes through the grid points one by one and collects the RSS values from the beacons. A vector of RSS can be created at each grid point as: $(rss_{bi}, rss_{bj}, rss_{bk})$. All of these vectors are collected to build the database. The second step aims to determine the number of grid points for each subarea. The reasons of knowing the range of each sub-area can be described in the following three reasons. Firstly, any changes in the network topology can be recovered by the RSS for the same grid points in the same sub-area. Secondly, by knowing the number of grids points in each sub-area the search space is reduced and enhanced. The RSS values are stored in DB as shown as in table 3.4

3.2.2 Stage 2: Dividing

In this stage, a group of beacon ID address is used as an identifier for each sub-area. Three beacons IDs can determine each subarea. Assume that the first sub-area is represented by Ac, and its identifier beacons are (B_1,B_2,B_3). Therefore, all RSS values that are received from these three beacons belong to sub-area A_c and each subarea has its own range of RSS, for example subarea A_c has the range from 1 to 30. A mobile target uses this range in the estimation phase to get the nearest three grid points database.

3.2.3 Stage 3: Estimation

In this stage, the location of a mobile node is calculated. This stage involves the following two steps:

1. To determine the subarea A_c where the mobile target is located; rely on the sub-area identifier used in previous stage.

2. To find the nearest three grid points to the target point that depends on the RSS values read from the beacons in the same subarea.

In the first step, to compute the location of a mobile node, the three anchors start measuring the RSS values of the mobile node. The ID address of the received beacons is used as an identifier to determine in which sub-area the mobile target is founded.

In the second step, to be more exact to locate the mobile node in sub-area, it necessary to find the nearest three points to mobile by comparing the mobile

RSS values with RSS values stored in DB for the same sub-area. This can be achieved by isolating the RSS values of each beacon in the same sub-area to two vectors V_{max} and V_{min}. The first vector includes all RSS values greater than the RSS value of mobile, and second vector includes all RSS values that are less than mobile RSS value. Select the small RSS value from V_{max} and the largest RSS value from V_{min}. Then, calculate the difference between these two values and mobile value to get the nearest one. This process is repeated for all three beacons in the sub-area. The three nearest points to mobile target is centroid to get the position of the mobile node.

3.2.4 Fingerprint Simulation Results

Our experiments are performed in a network with 15 nodes deployed in an area 40 × 20 meters, including five anchors device and 10 unknown devices. The unknown devices can be localized inside the study area. The percentage of the beacon is 33%, and the wireless communication range is 30 meters. The study area is divided into three sub-areas; each has its own identifier and numbers of grid points. The total number of grid points is 30 that cover the total study area. During our experiment, we start by collecting the RSS values of grid points and store them in database, during an offline stage. During our experiments, the execution of the algorithms starts by broadcasting HELLO message from mobile to all anchor nodes in its transmission range. Then, the mobile node receives the responses from the anchors and consequently measure the RSS values for all

Table 3.5: The accuracy of fingerprint system

Times (S)	Exact Coordination		Estimated Coordination		Error
	X	Y	X	Y	
1	19	14	17	15	2.236
2	12	6	15	5	3.162
3	40	15	42	13	3.828
4	27	10	27	8	2
5	39	3	39	2	2
6	43	10	41	10	2
7	31	10	29	9	2.236
8	23	7	20	8	3.162
9	15	16	17	15	2.236
10	44	3	45	5	2.236
AVG					2.422

beacons. After that, the identifier of the sub-area in which the mobile was found is determined. Then, all RSS values of grid points in that sub-area are compared with RSS values measured between the mobile node and the anchors to select the nearest three grid point to mobile node. Finally, the location of the mobile target is computed and sent to the gateway based on the the selected three grids points.

3.2.5 Performance Evaluation

1. **The Accuracy**

   Fingerprint localization system is evaluated by analyzing the error in the derived location. We computed the location error between the exact coordination of mobile node and the estimated location using equation 3.4. Table 3.5 provides the results of the fingerprint localization system. It contains the node ID, exact coordinates of all unknown nodes and the estimated coordinates of unknown nodes computed by fingerprint localization system. The

Fig. 3.13: Accuracy of fingerprint protocol

table shows that fingerprint localization gets the accuracy ranging between 2 meters, in the best case, and 3.162 meters, in the worst case. The average error is 2.422 meters, the results showed in table 3.4 are represented in figure 3.12. This means that the accuracy is excellent(less than 3 meters). These results accepted by applications that need a high accuracy.

Power Consumption

To estimate the power consumption of the fingerprint system, we can use the PowerTrce plug-in in COOJA simulator. It allows us to monitor the number of ticks per seconds for real time (rtimer), whic is a structure that present a real-time task. The collected data is shown in table 3.6:

The raw data in table 3.6 is used to calculate the power consumption of the mobile node at any time by using equation 3.5.

Table 3.7 provides the power consumption of fingerprint system. It contains the power consumption of CPU, LPM, Tx, Lx and Total power consumption.

Table 3.6: Fingerprint raw data (Ticks)

Times (s)	CPU	LPM	TX	LX
0	2382	63099	0	390
2	5583	125428	0	806
4	8789	187753	0	1222
6	16460	245615	1865	1612
8	31891	295715	1865	2637
10	35195	357943	1865	3469
12	38490	420180	1865	3469
14	46550	477650	3721	4111
16	50210	539518	3721	4953
18	53505	601755	3721	5369
20	56799	663993	3721	5785

Table 3.7: Power consumption of fingerprint system (mW)

Times (s)	CPU	LPM	TX	LX	Total
2	0.263754	0.155499	0	0.358008	0.777261
4	0.264166	0.155489	0	0.358008	0.777663
6	0.632071	0.144355	1.792831	0.335632	2.904889
8	1.271475	0.12499	0	0.882111	2.278576
10	0.272241	0.155247	0	0.358008	0.785496
12	0.2715	0.15527	0	0.358008	0.784777
14	0.664124	0.143377	1.78418	0.552502	3.144183
16	0.301575	0.154349	0	0.724622	1.180545
18	0.2715	0.15527	0	0.358008	0.784777
20	0.271417	0.155272	0	0.358008	0.784697

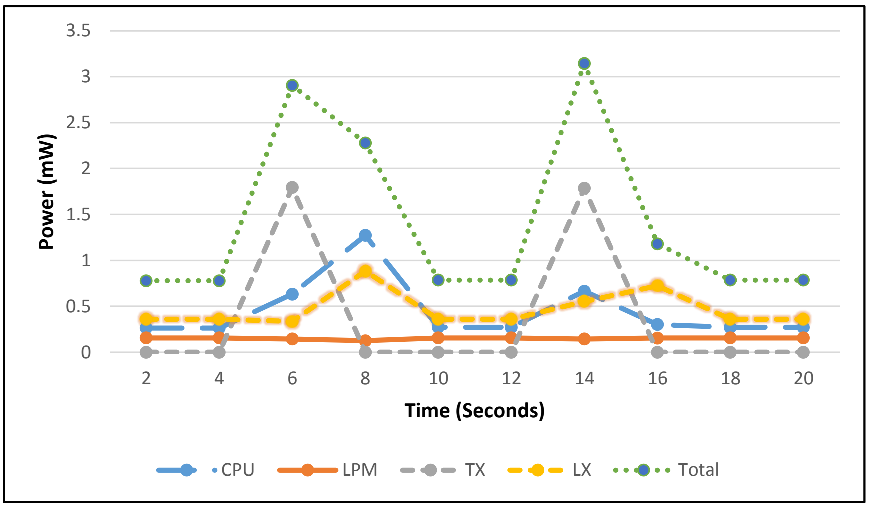

Fig. 3.14: Fingerprint power consumption

Figure 3.13 presents the power consumption for fingerprint system. It shows that the transmissions (Tx) reach the peak value at 6 and 14 seconds, because the mobile node replies to the anchor nodes that request to measure the RSS of the mobile. While the listening (Lx) reach the peak value at 8 and 16 seconds because it is the time of mobile node to move from one position to another position. Low Power Mode(LPM) is almost with constant value.

The duty cycle is calculated from the raw data in table 3.6 using equation 3.6. Figure 3.14 presents the duty cycle of the transmission and listening status. It shows the duty cycle as percentage or ratio between pulse duration of one state (Tx or Lx)and the total period (CPU and LPM) and represents the time it takes for a system to change from one status to another (Tx status to Lx status).

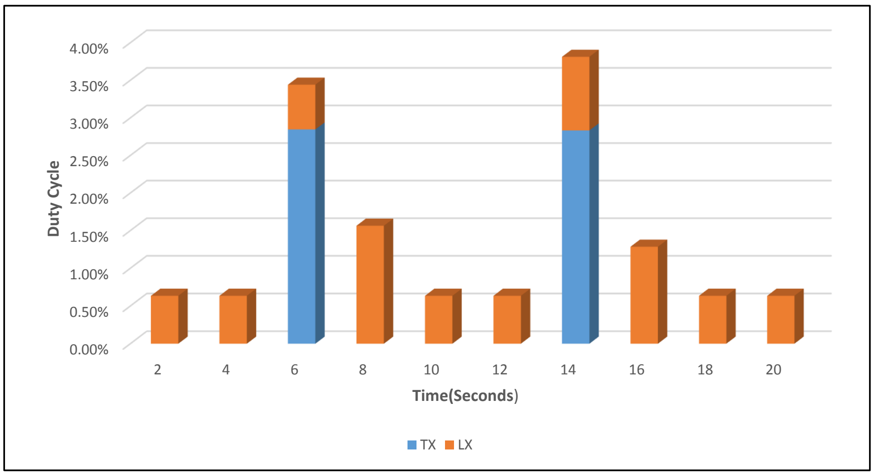

Fig. 3.15: Fingerprint duty cycle

CHAPTER 4

RANGE-FREE LOCALIZATION PROTOCOL

4.1 Localization Based on Centroid

Centroid localization depends on a great thickness of references so that each mobile node can get notification from a few beacons. Depending on the round radio propagation presumption, every mobile node computes its location by determining the center of the position of all received anchor nodes. The interest point of the centroid localization methodology is that doesn't require coordination between references nodes. This methodology offers reasonable localization precision. The algorithm implementation includes two stages.

In the first stage, all anchors send their coordinates, $B_j(X, Y)$ (j = 1 ..., n) where n is the total number of beacons, to a ll mobile sensor nodes with in their transmission area.

In the second stage, all mobile sensor nodes compute their location M (x,y) by getting the average for the coordinates of all n locations of the anchors in range, using equation 4.1:

$$M(X,Y) = \frac{1}{n}\sum_{j=1}^{n} B_j(X,Y) \tag{4.1}$$

Where, M (X ,Y): is the coordination of the Mobile target, n is the total number of beacons in the transmission area of mobile, and B (X, Y) is the coordination of the beacon nodes.

4.1.1 Centroid Simulation Results

Our experiment are performed in a network with 20 nodes deployed in an area 90 ×17 meters. In this network there is eight anchor devices and 12 unknown devices. The percentage of the beacon is 40%, while the wireless communication range is 28 meters.

By running COOJA simulator, the anchor nodes send their location information. Then, the unknown mobile receives the beacons' information of the first three beacons for which it calculates its position.

Nodes with IDs: 4,12 and 15 have the coordination of (33,52), (39,55) and (58,55) respectively.

4.1.2 Performance Evaluation

The performance of the localization system will be evaluated by two factors the accuracy and power consumption as follows.

Table 4.1: The accuracy of centroid localization system

Node ID	Exact Coordination		Estimated Coordination		Error(M)
	X	Y	X	Y	
1	14.76	55	19	55	4.24
2	26.65	60.37	23	61	3.7039708
3	40.44	57.74	39	55	3.0953514
4	49.92	63.83	49	61	2.9757856
5	64.81	55.64	59	55	5.8451433
6	21.18	59.85	19	55	5.3174148
7	25.49	65.64	29	61	5.8180495
8	38.65	60.37	39	55	5.381393
9	51.18	58.48	49	61	3.3320864
10	60.65	60.22	59	55	5.4745685
AVG					4.518

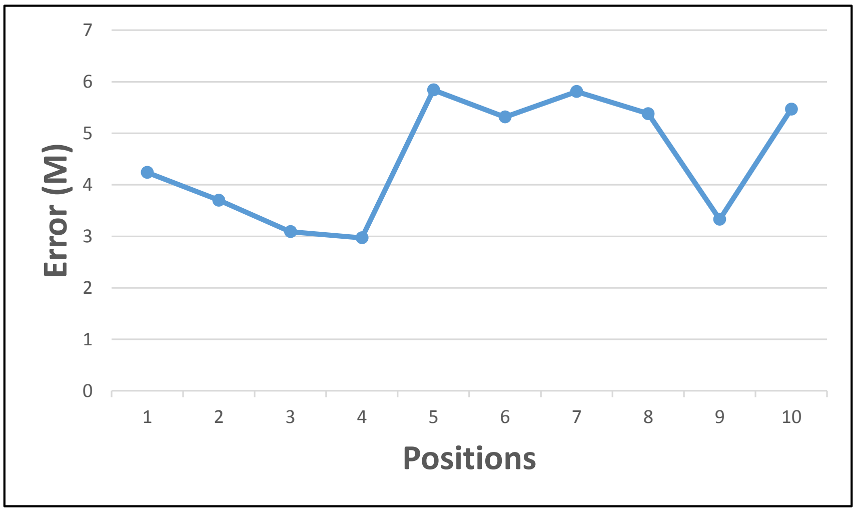

Fig. 4.1: Accuracy of centroid localization protocol

1. **The Localization Accuracy**

To evaluate localization accuracy of the system, the location error between the exact locations and estimated locations are computed by centroid localization, using equation 3.4.

Table 4.1 shows the achieved results and a summary of location errors for the centroid localization system. Table 4.1 contains the node ID, exact coordination of all unknown nodes and the estimated coordination of unknown nodes that are computed by centroid localization system. Base on the achieved results, the centroid localization accuracy ranging from 2.975785 meters, in (the best case), to 5.8180495 meters, in (the worst case). The average error is 4.518 meters, the results showed in table 4.1 represent in figure 4.1. The accuracy should be accepted by less number of applications than that of fingerprint localization system method. Also, the results show that all unknown nodes located in the same block that is covered by the same three anchors get the same location. This is because the average value of the three anchors has the same value.

2. **The Power Consumption**

   Likewise, in RSSI and fingerprint methods, to estimate the power consumption of the centroid system, we utilize the PowerTrace plug-in provided with COOJA simulator. This allows us to monitor the number of ticks per seconds for rtimer for the following status: CPU, LPM, Tx, and Lx, similar to what we did in RSSI and fingerprint approaches. The collected data is shown in table 4.2:

   Equation 3.5 used the data listed in table 4.2 to calculate the power consumption of the mobile node at any time. Figure 4.2 is the representation of data provided in table 4.3.

   We can see that Tx still remains constant with zero value. This is because no transmission is performed from the mobile node, also Lx state still constant

Table 4.2: Raw data of centroid system (Ticks)

Times	CPU	LPM	TX	LX
2	2500	63040	0	390
4	5809	125262	0	806
6	9138	187464	0	1222
8	12488	249646	0	1638
10	15862	311804	0	2054
12	19236	373961	0	2470
14	22610	43618	0	2886
16	25984	498275	0	3302
18	29358	560432	0	3718
20	32733	622589	0	4134

Table 4.3: Power consumption of centroid system (mW)

Times	CPU	LPM	TX	LX	Total
2	0.009997	0.000626625	0	0.071602	0.082225
4	0.010058	0.000626424	0	0.071602	0.082286
6	0.010121	0.000626223	0	0.071602	0.082349
8	0.010194	0.000625981	0	0.071602	0.082421
10	0.010194	0.000625971	0	0.071602	0.082421
12	0.010194	0.000625971	0	0.071602	0.082421
14	0.010194	0.000625971	0	0.071602	0.082421
16	0.010194	0.000625971	0	0.071602	0.082421
18	0.010197	0.000625971	0	0.071602	0.082424
20	0.010197	0.000625971	0	0.071602	0.082424

with .071602 value. While LPM and CPU have a little change in their values.

The duty cycle can be also calculated from the raw data in table 4.2 using the equation 3.5. Figure 4.3 presents that Lx status has a full time 100% as compared to Tx due to t no transmission from the unknown nodes to the anchor nodes.

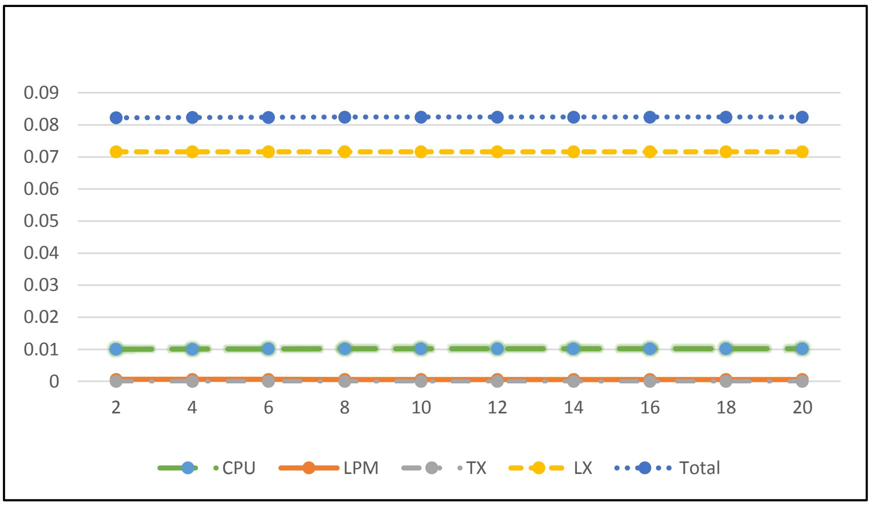

Fig. 4.2: Power consumption of centroid system

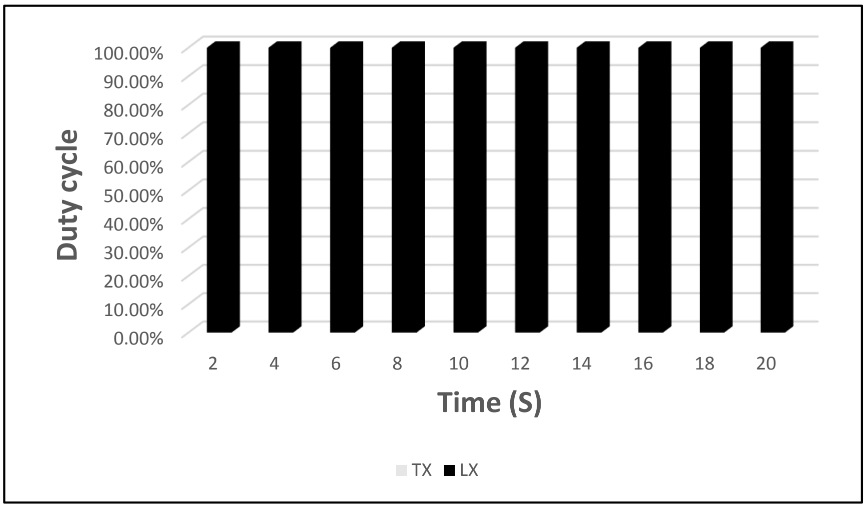

Fig. 4.3: Duty cycle of centroid system

4.2 Localization Based on DV-Hop

In the DV-Hop algorithm, the anchor broadcasts a packet, in its transmission range, in the network. The transmitted packet contains the coordinate of this anchor node. It also contains a hop metric with an initial value equals 1. The packet is broadcasted in the network and the hop-count increment by 1 per hops.

The DV-Hop implementation includes three steps. In the first step, every anchor broadcast its position data and hops count in the network. This way ensures that all anchor nodes receive location information with the minimum hop count in the network topology. In the second stage, each anchor node computes the average distance per hop using equation 4.2:

$$ADH = \frac{\sum_{j \in S, j \neq i} \sqrt{(X_i - X_j)^2 + (Y_i - Y_j)^2}}{\sum_{j \in S, j \neq i} h_{i,j}} \tag{4.2}$$

Where (x_i, x_j) and (y_i, y_j) are the actual and calculated coordinates of anchor i and j, $h_{i,j}$ is the hop metric value between two anchor nodes i and j and S represents the set of anchors.

After computing the average distance, each anchor broadcast its average distance of hop (ADH) in its transmission range. Before this step finishes, each beacon node will have a routing table that includes the destination node ID, X coordinate, Y coordinate and minimum hop count. Consequently, each beacon node will contain all the necessary information about all beacons beacons in the network. The unknown node receives the first ADHs from the beacons and discards the later ones. After that, the unknown node uses the received ADHs to calculate the distances to the first three anchors by multiplying each ADH with a number of hops to its anchor. In the third step, the position of the unknown nodes are computed using trilateration equation 3.3.

Table 4.4: The accuracy of DV-Hop system

Node ID	Exact Coordination		Estimated Coordination		Error (M)
	X	Y	X	Y	
1	13.24	41.21	14	38	3.3016616
2	16.25	35.85	14	38	3.1120733
3	29.97	52.57	29	55	2.616448
4	29.4	52.66	29	55	2.3739419
5	45.47	40.99	47	39	2.5101793
6	46.82	39.95	47	39	0.9669023
7	47.47	40.78	47	39	1.8410052
8	10.83	38.83	14	38	3.2768583
9	12.78	39.5	14	38	1.9334942
10	45.2	42.1	47	39	3.5846897
AVG					2.551

4.2.1 DV-Hop Simulation Results

With the same scenario in section 4.2.1. By running COOJA simulator, nodes start to exchange their information packets with the anchors for building their routing table. Routing tables of all beacons contain all next hop, coordinates as well as the minimum hops of all other anchor nodes in the network.

Beacons broadcast the ADH within the proximity of their transmission area. This allow the unknown nodes to calculate the distance to the anchors to be used in the trilateration process of computing the location of unknown nodes. The final coordination of node with ID 7 and 10 are calculated in which mobile node ID: 7 with coordinate (47,39) and mobile node ID10 with coordinate (29,55).

4.2.2 Performance Evaluation

The performance of the localization system will be evaluated by two factors the accuracy and power consumption as follows.

Fig. 4.4: Accuracy of DV-Hop localization protocol

1. **The Accuracy**

   To analysis and evaluate this system, we used the data presented in table 4.4 and calculated the location error, using equation 3.4.

   Table 4.4 provides a summary of the location errors in the network.

   This table contains the node ID, the exact coordination of all unknown nodes and the estimated coordination of unknown nodes computed by the DV-Hop localization system. Table 4.4 shows that DV-Hop localization accuracy range between 0.9669023 meters in (the best case), and 3.5846897 meters in (the worst case). The average error is 2.551 meters, the results showed in table 4.4 represented in figure 4.4. The distance is the same for all unknown nodes in the same block (covered by same three anchor nodes).

2. **Power Consumption**

   To calculate the power consumption, we use PowerTrce plug-in provided by

Table 4.5: Raw data of DV-Hop system (Ticks)

Times	CPU	LPM	TX	LX
2	2395	63116	0	390
4	10215	120822	0	1486
6	19559	177005	0	2580
8	28902	233188	0	3674
10	38270	289346	0	4768
12	47638	345504	0	5862
14	57006	401662	0	6956
16	66374	457820	0	8050
18	75743	513978	0	9144
20	8511	570136	0	10238

Table 4.6: DV-Hop Power consumption (mW)

Times	CPU	LPM	TX	LX	Total
2	0.023626	0.000581	0	0.188643	0.21285
4	0.02823	0.000566	0	0.188298	0.217095
6	0.028227	0.000566	0	0.188298	0.217092
8	0.028303	0.000566	0	0.188298	0.217167
10	0.028303	0.000566	0	0.188298	0.217167
12	0.028303	0.000566	0	0.188298	0.217167
14	0.028303	0.000566	0	0.188298	0.217167
16	0.028306	0.000566	0	0.188298	0.21717
18	0.028303	0.000566	0	0.188298	0.217167
20	0.028342	0.000565	0	0.188298	0.217206

COOJA. Table 4.5 shows the achieved results from the monitored number of ticks per second for real time for the following: CPU, LPM, Tx, and Lx.

The data presented in Table 4.5 is used to calculate the power consumption of the mobile node at different time, using the equation 3.5. The results presented in table 4.6 is also represented in figure 4.5. The duty cycle is also calculated from the raw data in table 4.5 using equation 3.6. Figure 4.6 presents that Lx status has a full time 100% compared to Tx as there is no transmission from the unknown nodes to the anchor nodes.

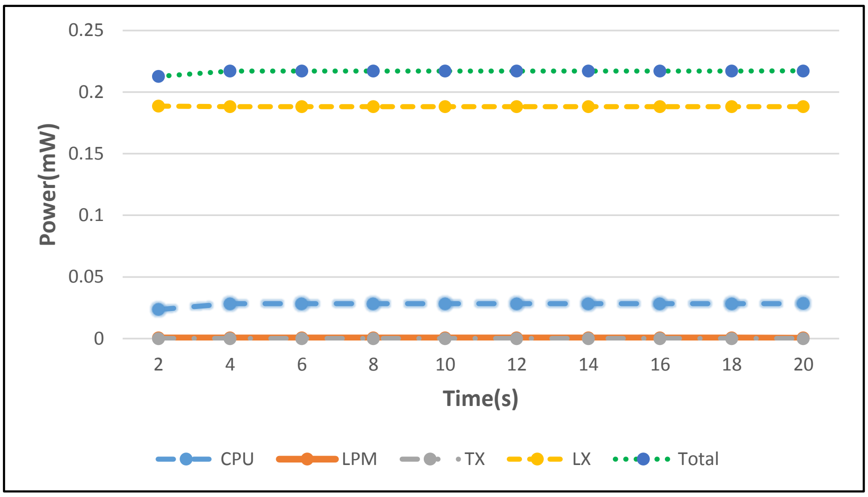

Fig. 4.5: DV-Hop power consumption

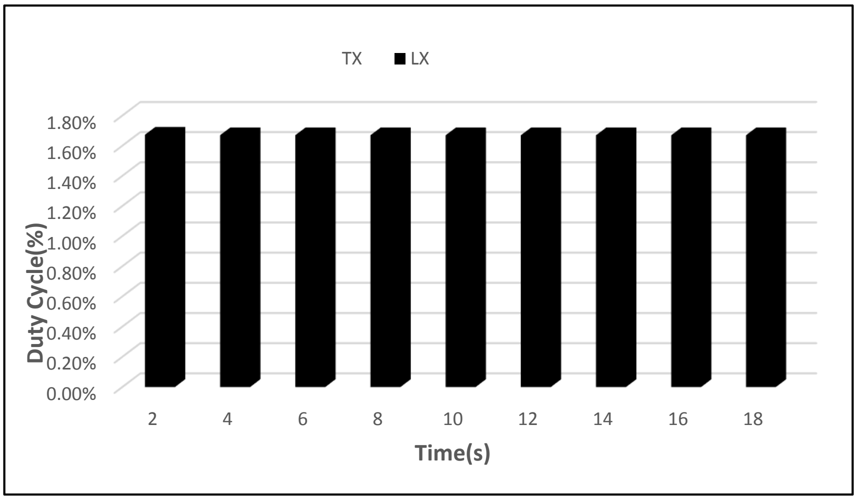

Fig. 4.6: DV-Hop duty cycle

CHAPTER 5

CONCLUSION AND FUTURE WORK

A performance evaluation in terms of localization accuracy and power efficiency between range-based and range-free localization protocols has been conducted using Cooja simulator. It is worth mentioning that this is the first time Cooja simulator is used in such study. The study is conducted using TmoteSky sensors. The anchor nodes were arranged in triangle topology and every moving target was in the range of at least three anchors. The results showed that RSS localization accuracy range is between 0.4346 meters for the best case and 2.44233 meters for the worst case and average error is 1.447 meters. The fingerprint localization gets the accuracy range is between 2 and 3.162 meters and the average error is 2.422 meters. For centroid localization, the accuracy range is between 2.976 to 5.818 meters and the average error is 4.518 meters. Finally, for DV-hop localization, the accuracy range is between 0.967 to 3.585 meters and the average error is 2.551 meters. We conclude that RSSI and fingerprint protocol have the best average localization accuracy, however, DV-hop protocol is very close to fingerprint . Moreover, fingerprint protocol has an overhead of setting the network and measuring all the points in the grid. For the power performance, both DV-hop and Centroid protocols outperform fingerprint and RSSI protocols in terms of stability and power consumption. The comparison between four protocols: RSS, Fingerprint, Centroid and DV-hop in term of accuracy and power consumption are showed in figure 5.1 and 5.2 respectively. In future work, we plan to test another sensor like Zolertia and MICAz.

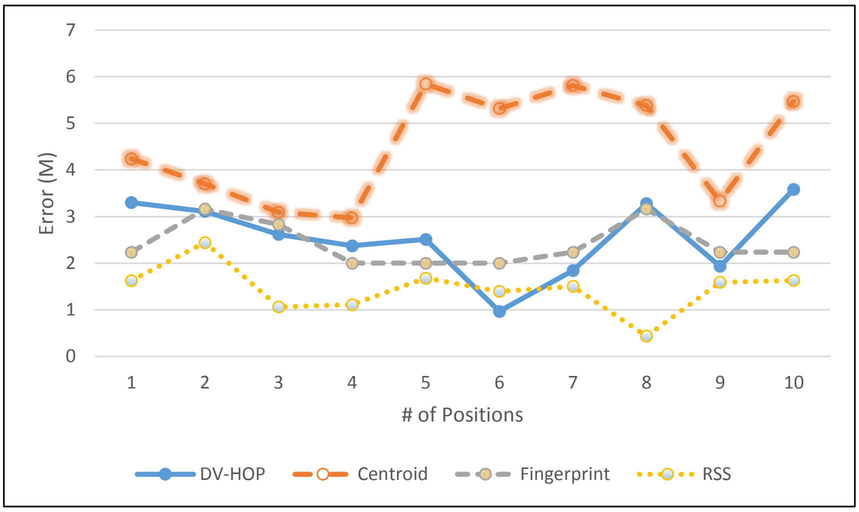

Fig. 5.1: Average error comparison between protocols

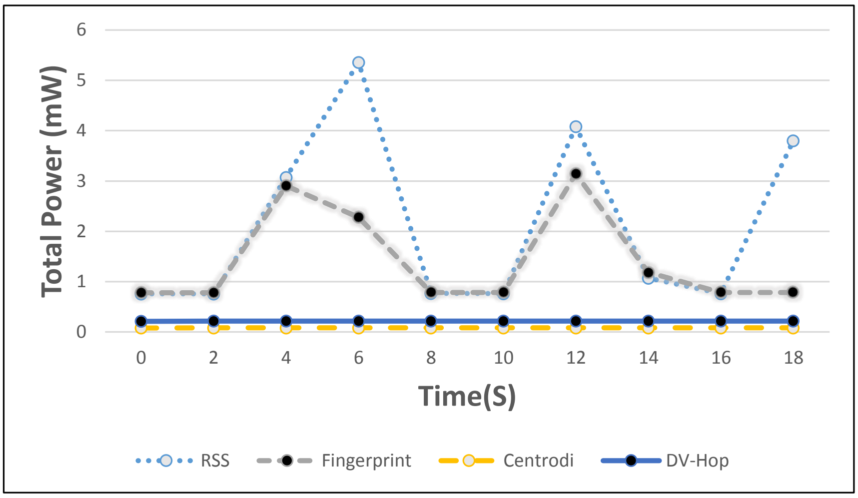

Fig. 5.2: Average power consumption comparison between protocols

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Vitae

Essa Qasem Shahra
Computer Engineering King Fahd University of Petroleum and Minerals,
Dhahran, KSA.

Mobile: 00966-508027117

E-Mail: eissa.qassim@gmai.com

EDUCATION

2014 – 2016 **Master of Science**, **in Computer Networks,** College of Computer Sci & Engineering, King Fahd University of Petroleum and Minerals (KFUPM), Dhahran, Saudi Arabia,

2004 - 2009 **Bachelor's Degree**, **in Engineering & IT,** Department of Information Technology**,** Faculty of Engineering & Information Technology, Taiz University, Taiz, Yemen

PUBLICATIONS

1. **JOURNALS**
   - **Essa Qasem Shahra, Tarek Rahil Sheltami** "A Comparative Study of Range-Free and Range-Based Localization Protocols for Wireless Sensor Network: Using COOJA Simulator." International Journal of Distributed Systems and Technologies (IJDST) 8.1 (2017): 1-16. [PUBLISHED].
   - **Tarek R. Sheltami, Essa Q. Shahra** "Localization and Power Performance of Three Localization Protocols for Wireless Sensor Network Using COJA", Journal of Ambient Intelligence and Humanized Computing (JAIHC) [ACCEPTED].
2. **CONFERENCE**
   - **Essa Q. Shahra , Tarek R. Sheltami** "Comparative Study of Fingerprint and Centroid Localization Protocol Using COOJA." Procedia Computer Science 98 (2016): 16-23.. [PUBLISHED].

MASTER TERM PROJECTS/RESEARCHS

- **Advanced Computing Company (ACC):** Computer Network Design.
- **Mashup Application:** Client Server Programming.
- **Modeling Internet Applications with Event Graphs.** Modeling and Simulation.
- **Social Networking Services (SNS).** Management Information Systems.
- **A Survey on SQL Injection:** Computer and Network Security.
- **Location Based Service (LBS):** Geographic Information System.
- **COOJA Simulator Tool:** Independent Research.

TRAINING COURCES AND CERTIFICATES

2010 CCNA Cisco Certificated Networking Associate by Public Telecom, Institute, Taiz, Yemen.
2007 Software Projects Administration, Faculty of IT, Teshreen University, Lattakia, Syrian Arab Republic.

WORK EXPERINCES

- **2010-2012** Teaching assistance: Taiz university faculty of Engineering**.**
- **2010-2013** IT Administrator: Yemen Post Office, Taiz Branch.

PROFESSIONAL SKILLS

- **Network Simulators Environments**: COOJA, Opnet, Matlab
- **Internet Technology:** ASP, PHP, MySQL, AJAX, JQuery, XHTML, CSS, JavaScript.
- **Databases:** MySQL, SQL Server, and Oracle.
- **Operating Systems:** Linux and Windows.
- **Programming Languages:** C#**,** Java, C, C++, and Visual C++.
- **Frameworks:** MFC, Java and Visual Studio.

LANGUAGE

- Arabic (native).
- English: V. Good (Reading, Writing and Speaking).

REFERENCES

Available upon request.